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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-21 AND J4-1801-22)

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M. R. Collier

ARO, Inc.

June 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-21 AND J4-1801-22)

M. R. Collier

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine; and engineering liaison was provided by Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on December 21, 1967, and January 4, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on March 21, 1968.

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This technical report has been reviewed and is approved.

Harold Nelson, Jr. Captain, USAF AF Representative, LRF Directorate of Test	Roy R. Croy, Jr. Colonel, USAF Director of Test

ABSTRACT

Nine firings of the J-2 rocket engine were conducted in Test Cell J-4 of the Arnold Engineering Development Center, Large Rocket Facility, during test periods J4-1801-21 and 22. The firings were accomplished at pressure altitudes ranging from 95,000 to 112,000 ft at engine start. The objectives of these tests were to investigate S-II/S-V start condition effects on engine start, gas generator ignition characteristics, and fuel pump operation. Engine thermal condition extremes for S-II flight configuration were duplicated. Satisfactory engine operation was obtained. Accumulated firing duration was 111.6 sec.

CONTENTS

APPENDIXES

I. ILLUSTRATIONS

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, time at which helium control and ignition phase solenoids are energized
GG	Gas generator
LOVT	Main oxidizer valve position
MFV	Main fuel valve
MOV	Main oxidizer valve
PU	Propellant utilization valve
STDV	Start tank discharge valve
TGGO	Gas generator outlet temperature
t_0	Time at which opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, indication of time duration of engine vibration measurement in excess of 150 g rms at frequencies between 960 and 9000 Hz

SUBSCRIPTS

e	Exit
f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The nine firings reported herein were conducted during test periods J4-1801-21 and 22 on December 21, 1967, and January 4, 1968, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate J-2 engine S-II/S-V start condition effects on engine start, gas generator ignition characteristics, and fuel pump operation characteristics during start tank discharge. These firings were accomplished at pressure altitudes ranging from 95, 000 to 112, 000 ft (geometric pressure altitude, Z, Ref. 1) at engine start, with predicted thermal conditions for S-II start.

Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230, 000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self-lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases that bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant pre-valves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell, (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule, and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, main oxidizer valve second-stage actuator, and start tank discharge valve opening control line. Helium was routed internally through the crossover duct and thrust chamber, and externally over other components.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and

fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units, (2) voltage substitution for the thermocouples, (3) frequency substitution for shaft speeds and flowmeters, and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components that required temperature conditioning were the thrust chamber, the crossover duct, start tank discharge valve opening control line, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Eight engine firings, and one engine start with cutoff 400 msec after the main-stage control solenoid was energized, were conducted

during test J4-1801-21 on December 21, 1967, and test J4-1801-22 on January 4, 1968, for a total duration of 111.6 sec. All firings were in support of the S-II/S-V J-2 Engine Developmental Program. Thermal conditioning of the engine and selected engine components was accomplished to simulate the predicted S-II flight thermal environment. All engine starts were made with the propellant utilization valve in the null (0-deg) position. Thirty-second firings were conducted using a propellant utilization valve excursion from null to full closed at approximately t_0 + 10 sec which changed the mixture ratio from 5.0 to 5.5. All firings were preceded by a one-second fuel lead. The following are objectives and a brief summary of results.

Firing	Test Objectives	Results
21A	Investigate S-II start transient characteristics using maximum start gas energy, warmest expected thrust chamber, and high fuel and oxidizer pump inlet pressures.	Start conditions resulted in a fast start and late main oxidizer valve second-stage movement which produced a second peak gas generator temperature of 1885°F. Time to 550 psia chamber pressure was 1.875 sec.
21B	Investigate S-II start transient characteristics using low fuel and high oxidizer pump inlet pressures, warmest expected thrust chamber, and high start gas energy.	Stall margin during start tank discharge and fuel pump acceleration was significantly lower than firing 21A, which was identical except for fuel pump inlet pressure; however, adequate margin was maintained on this firing.
21C	Investigate S-II start transient characteristics using low fuel and high oxidizer pump inlet pressure, warmest expected thrust chamber, and high start gas energy.	This firing was identical to firing 21B, except for start tank pressure and temperature which provided a slight increase in energy. Fuel pump spinup was higher than on 21B which provided higher gas generator power and, thus, higher hydraulic torque on the main oxidizer valve, resulting in higher second peak gas generator temperature.

Firing	Test Objectives	Results
21D	Investigate S-II start transient characteristics using coldest expected thrust chamber, high start gas energy, and low fuel and high oxidizer pump inlet pressures.	The combination of cold thrust chamber and low fuel pump inlet pressure reduced gas generator fuel injection pressure to a low value which caused delayed ignition or poor gas generator burning for 0.05 sec. This resulted in low gas generator power for pump acceleration.
22A	Investigate S-II start transient characteristics using coldest expected thrust chamber, high start gas energy, low fuel and high oxidizer pump inlet pressures.	This firing was identical to firing 21D with the exception of start tank pressure and temperatures which were slightly lower. Results of the two firings were the same.
22B	Investigate S-II start transient characteristics using coldest expected thrust chamber, maximum start gas energy, and high oxidizer and fuel pump inlet pressures.	This firing was identical to firing 22A with the exception of fuel pump inlet pressure which was 15.4 psi higher than firing 22A. This higher fuel inlet pressure resulted in more nearly normal gas generator operation when compared with firing 22A.
22C	Investigate S-II start transient characteristics using coldest expected thrust chamber, low fuel and high oxidizer pump inlet pressures, and high start gas energy.	This firing was identical to firing 21B with the exception of thrust chamber temperature. The colder thrust chamber temperature for this firing resulted in reduced fuel system resistance and, therefore, lower gas generator fuel system pressures.
22D	Investigate S-II start transient characteristics using warmest expected thrust chamber, low fuel and high oxidizer pump inlet pressures, and nominal start gas energy at low temperature.	This firing was identical to firing 21B with the exception of start tank pressure. Lower start tank pressure resulted in decreased fuel and oxidizer pump speeds and discharge pressures.

Firing	Test Objectives	Results
22E	Investigate S-II fuel pump start transient characteristics using lower than minimum specification fuel pump inlet pressure.	Fuel pump operation appears normal throughout this firing which was terminated at 0.873 sec. Adequate stall margin was maintained and no evidence of fuel pump cavitation was seen.

Specific test requirements and results are summarized in Table VI. Start and shutdown times of engine valves are presented in Table VII. Included in this table are prefiring valve times obtained from the final sequence run. Engine performance data are tabulated in Table VIII. Methods of calculation are described in Appendix IV. The pressure and temperature at engine start are shown in Fig. 8 for the pump inlets, start tank, and helium tank.

The presentation of the test results in the following sections consists of a discussion of each engine firing with pertinent comparisons. The data presented are those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-21A

Firing 21A was 32.575 sec in duration after a 1-sec fuel lead. A propellant utilization valve excursion from null to full closed was made at about t_0 + 10 sec (changing the mixture ratio from 5.0 to 5.5). All engine start conditions were within specified target limits, except thrust chamber throat (TTC-1P) temperature which was warmer than desired by about 2°F. A summary of engine test requirements and results is presented in Table VI. The temperature conditioning time histories of the required components are shown in Fig. 9. Test cell pressure altitude at engine start was 95,000 ft. Test cell pressure during the firing is presented in Fig. 10, along with engine chamber pressure which reflects the propellant utilization valve excursion at about t_0 + 10 sec.

The start conditions for this firing resulted in early main chamber ignition (t_0 + 0.950); however, the time to 550-psia chamber pressure was not the fastest observed during this test period. The first gas generator temperature peak was 1610°F with a second peak of 1885°F. This second peak resulted from the late movement of the main oxidizer

valve from the 14-deg position. Figure 11 presents selected engine start and shutdown transient parameters. Figure 12 presents fuel pump transient performance.

4.2.2 Firing J4-1801-21B

Firing 21B was 7.588 sec in duration after a 1-sec fuel lead. All engine start conditions were within specified target limits with exception of the main oxidizer valve second-stage actuator temperature which was 1°F colder than specified. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 13. Test cell pressure altitude at engine start was 112,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 14.

Firing 21B start conditions were identical to firing 21A with the exception of fuel pump inlet pressure, which was 13.1 psi lower than for 21A. Gas generator temperature peaked at 1840°F; a second peak of 1840°F was observed. This first peak temperature and decrease in fuel pump stall margin are the only significant differences noted in the start transient characteristics of firing 21B, as compared with firing 21A. Selected engine start and shutdown transient parameters are presented in Fig. 15. Fuel pump transient performance is presented in Fig. 16.

4.2.3 Firing J4-1801-21C

Firing 21C was 7.588 sec in duration after a 1-sec fuel lead. All engine start conditions were within specified target limits. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 17. Test cell pressure altitude at engine start was 107,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 18.

Firing 21C start conditions were identical to firing 21B with the exception of start tank pressure and temperature which combined to provide slightly higher start gas energy. Start tank pressure was 100 psi higher and temperature was 60°F warmer on firing 21C, as compared with 21B. The pressure increase tends to spin both pumps higher, whereas the warmer temperature lowers the oxidizer pump peak spin speed; the net result on firing 21C was higher fuel pump spin speed with no significant change in oxidizer pump spin speed. The first gas generator temperature peak was slightly lower on firing 21C (1795°F),

while the second peak was higher at 2125°F. This second peak temperature occurred when the main oxidizer valve second stage moved only slightly (about 1 deg) between t_0 + 1.145 sec and 1.305 sec. Start and shutdown transient parameters are presented in Fig. 19. Fuel pump transient performance is presented in Fig. 20.

4.2.4 Firing J4-1801-21D

Firing 21D was 7.588 sec in duration after a 1-sec fuel lead. All engine start conditions were within specified target limits. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 21. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 22. Test cell pressure altitude at engine start was 108,000 ft.

Firing 21D utilized a -275°F thrust chamber throat target temperature which corresponds to the coldest expected S-II thrust chamber temperature. This temperature was the only difference in starting conditions between firings 21C and 21D. The low thrust chamber temperature on firing 21D, in conjunction with low fuel inlet pressure, resulted in low-grade (or lack of) combustion in the gas generator for a period of about 0.05 sec after ignition of the initial mixture occurred at about t_0 + 0.65 sec. The low-grade combustion was the result of low fuel system pressures caused by the cold thrust chamber (low thrust chamber fuel system resistance). Another result of the low-grade gas generator combustion is seen in the decreased fuel pump acceleration in the time period between gas generator fuel and oxidizer valves open, and main chamber ignition at t_0 + 0.985 sec, as compared with firing 21C for the same time period. Oxidizer pump speed was also affected. Oxidizer pump speed decreased about 500 rpm more than on firing 21C during this same time period.

Firing 21D also experienced combustion instability for a period of 120 msec which began at main chamber ignition. This is a characteristic of cold thrust chamber firings as reported in Ref. 5. Start and shutdown transient parameters are presented in Fig. 23. Figure 24 presents fuel pump transient performance. Figure 25 presents comparisons of parameters for firings 21D and 21C which illustrate the effects of cold thrust chamber temperature on start transient characteristics.

4.2.5 Firing J4-1801-22A

Firing 22A was 32.576 sec in duration after a 1-sec fuel lead. All engine start conditions were within specified target limits, except oxidizer pump inlet temperature which was 0.1°F colder than required. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 26. Test cell pressure altitude at engine start was 101,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 27.

Firing 22A starting conditions were similar to 21D; the only significant differences were start gas pressure and temperature. The average thrust chamber temperature was the same as that of 21D, although the throat temperature was 25°F warmer as read on TTC-1P which was within target limits. The results of firing 22A are, therefore, similar to those of firing 21D. Gas generator pressures are comparable to those obtained on firing 21D and indicate low-grade gas generator combustion in the time period between gas generator valves open and main chamber ignition (t_0 + 0.64 and 0.985). Firing 22A fuel system pressures are slightly lower in the time period between t_0 + 0.6 sec and t_0 + 1.0 sec than for firing 21D because of lower fuel pump spinup, which resulted from 20-psi lower start tank pressure.

Start and shutdown transient parameters are presented in Fig. 28. Fuel pump transient performance is presented in Fig. 29.

4.2.6 Firing J4-1801-22B

Firing 22B was 7.586 sec in duration after a 1-sec fuel lead. All engine start conditions were within specified target limits except crossover duct temperature (TFTD-8) and start tank discharge valve closing control line temperature. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 30. Test cell pressure altitude at engine start was 109,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 31.

Firing 22B starting conditions were identical to those of 22A, except for fuel pump inlet pressure which was 15.4 psi higher. Comparison of start transient parameters for these two firings shows the effect of fuel pump inlet pressure on the gas generator. Firing 22B, which utilized high (41-psia) fuel pump inlet pressure, exhibited a relatively normal gas generator ignition transient. Ignition was attained as the gas generator oxidizer valve opened, and adequate gas generator fuel injection pressure was maintained to sustain combustion.

Start and shutdown transient parameters are presented in Fig. 32. Fuel pump transient performance is presented in Fig. 33. Figure 34 presents gas generator transient parameter comparisons for firings 22A and 22B.

4.2.7 Firing J4-1801-22C

Firing 22C was 7.588 sec in duration after a 1-sec fuel lead. Engine start conditions that were not within specified target limits were fuel pump inlet pressure and temperature and crossover duct temperatures (TFTD-2 and -8). A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 35. Test cell pressure altitude at engine start was 109,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 36.

Firing 22C compares with 21B in starting conditions, except for thrust chamber temperature which was approximately 200°F colder on 22C than on 21B. The result of the reduced thrust chamber resistance is reflected in reduced gas generator fuel injection pressure which caused a delay in gas generator ignition of about 0.08 sec after gas generator oxidizer valve opening.

Start and shutdown transient parameters are presented in Fig. 37. Fuel pump transient performance is presented in Fig. 38. Figure 39 presents gas generator transient parameter comparisons for firings 22C and 21B.

4.2.8 Firing J4-1801-22D

Firing 22D was 7.589 sec in duration after a 1-sec fuel lead. Engine start conditions that were not within specified target limits were crossover duct temperature (TFTD-8) and start tank discharge valve opening control line temperature. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 40. Test cell pressure altitude at engine start was 112,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 41.

The results of firing 22D, when compared with firing 21B results, show the effect of a 100-psi decrease in start tank pressure. Both propellant pumps spun up to a lower level during start tank discharge on firing 22D which resulted in lower oxidizer and fuel system pressures. These lower pressures decreased the main oxidizer valve hydraulic torque, resulting in a faster second-stage opening. Lower pump

discharge pressures also result in later main chamber ignition and longer time to 550-psia chamber pressure. The decreased main oxidizer valve hydraulic torque also produced a lower gas generator second temperature peak, a result of the earlier movement of the valve from the 14-deg position. The first peak temperatures were only 65°F different.

Start and shutdown transient parameters are presented in Fig. 42. Fuel pump transient performance is presented in Fig. 43. Figure 44 presents start transient parameter comparisons for firings 22D and 21B.

4.2.9 Firing J4-1801-22E

Firing 22E was 0.873 sec in duration after a 1-sec fuel lead. Engine start conditions that were not within specified target limits were crossover duct temperature (TFTD-8) and start tank discharge valve opening control line temperature. A summary of test requirements and results is presented in Table VI. The required component temperature conditioning time histories are presented in Fig. 45. Test cell pressure altitude at engine start was 112,000 ft. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 46.

Firing 22E was conducted, as planned, using pump inlet pressures lower than specification minimum to evaluate fuel pump operation. Fuel pump inlet pressure at engine start for this firing was 22.3 psia. Pump head-flow data indicate a wide stall margin until cutoff occurred at t_0 + 0.873 sec. Pump head-flow data do not show any evidence of pump cavitation, although flow is approximately 600 gpm lower at cutoff on 22E than at the corresponding time on 22B which used 45-psia fuel pump inlet pressure. Firing 22E gas generator pressures indicate late ignition and poor burning, as evidenced on other cold thrust chamber/low inlet pressure firings (21D, 22A, and 22C) reported herein.

Engine transient parameters are presented in Fig. 47. Fuel pump transient performance is presented in Fig. 48.

SECTION V
SUMMARY OF RESULTS

The results of the nine firings conducted during Tests J4-1801-21 and 22 are summarized as follows:

1. Low fuel inlet pressure in conjunction with cold thrust chamber temperature resulted in delayed gas generator ignition and low

gas generator power until main chamber ignition was obtained. Low inlet pressure or cold thrust chamber temperature alone did not produce this result.

2. Low fuel pump inlet pressures did not significantly increase the gas generator temperature peak value. Fuel pump stall margin during start tank discharge was reduced; however, an adequate margin was maintained on these low inlet pressure firings.

3. Fuel pump operation appeared satisfactory, exhibiting wide stall margin and no evidence of cavitation when an inlet pressure of 22.5 psia was used in conjunction with cold thrust chamber and high starting energy.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

2. Dougherty, N. S., Jr. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-20)." AEDC-TR-68-101, June 1968.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook (Sixth Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

5. Collier, M. R. and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1554-26)." AEDC-TR-67-145 (AD821541), October 1967.

APPENDIXES

I. ILLUSTRATIONS

II. TABLES

III. INSTRUMENTATION

IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

Fig. 1 Test Cell J-4 Complex

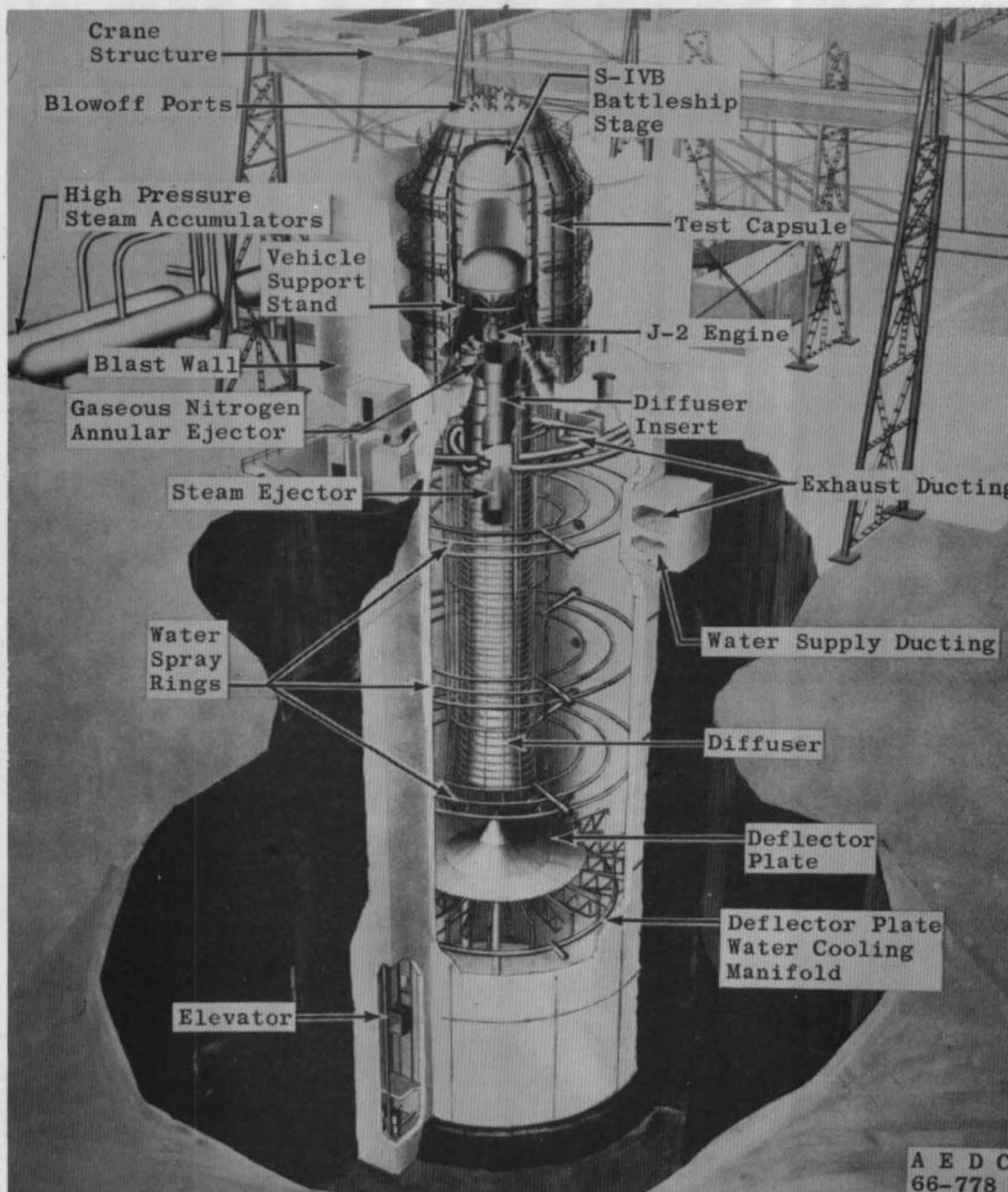


Fig. 2 Test Cell J-4, Artist's Conception

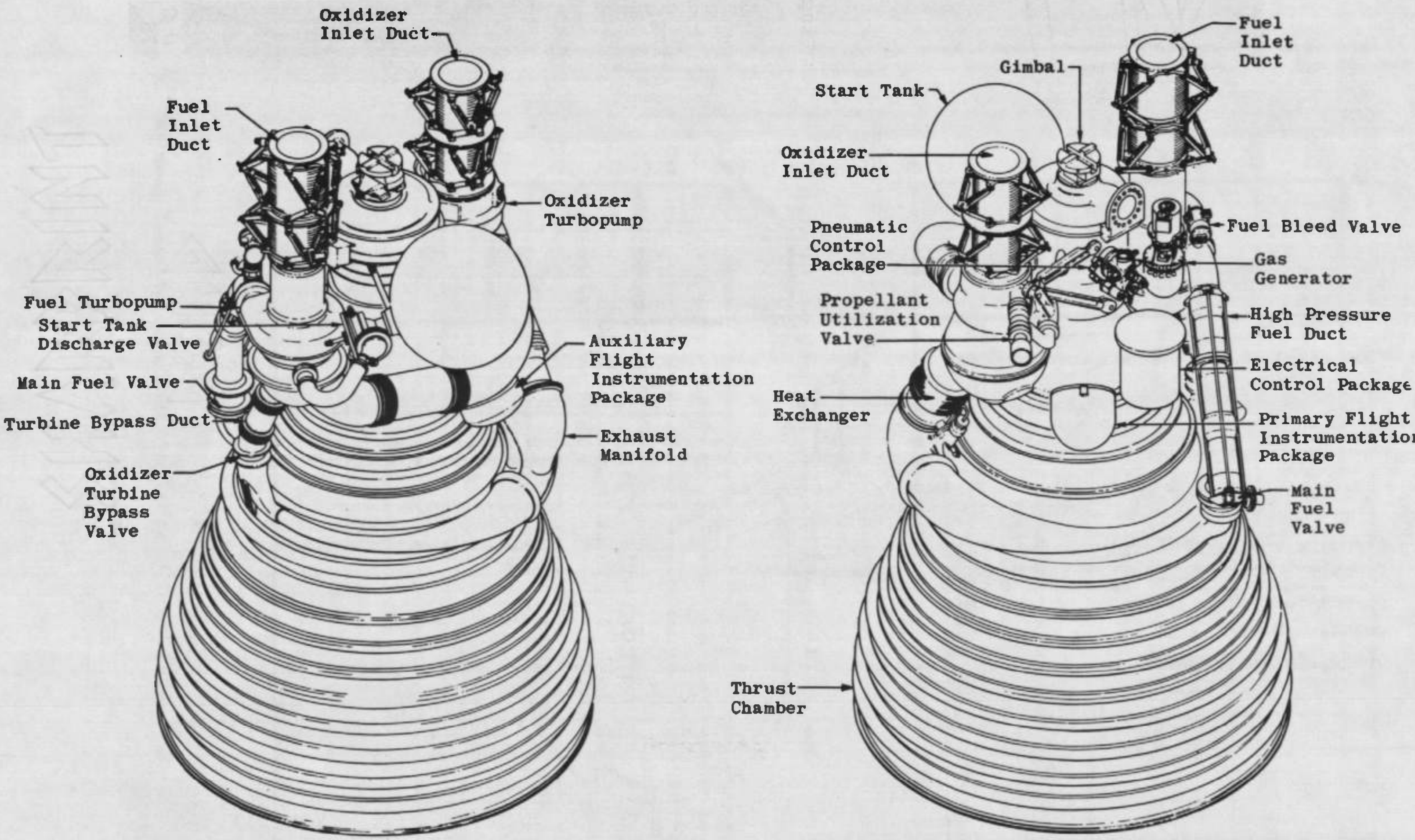


Fig. 3 Engine Details

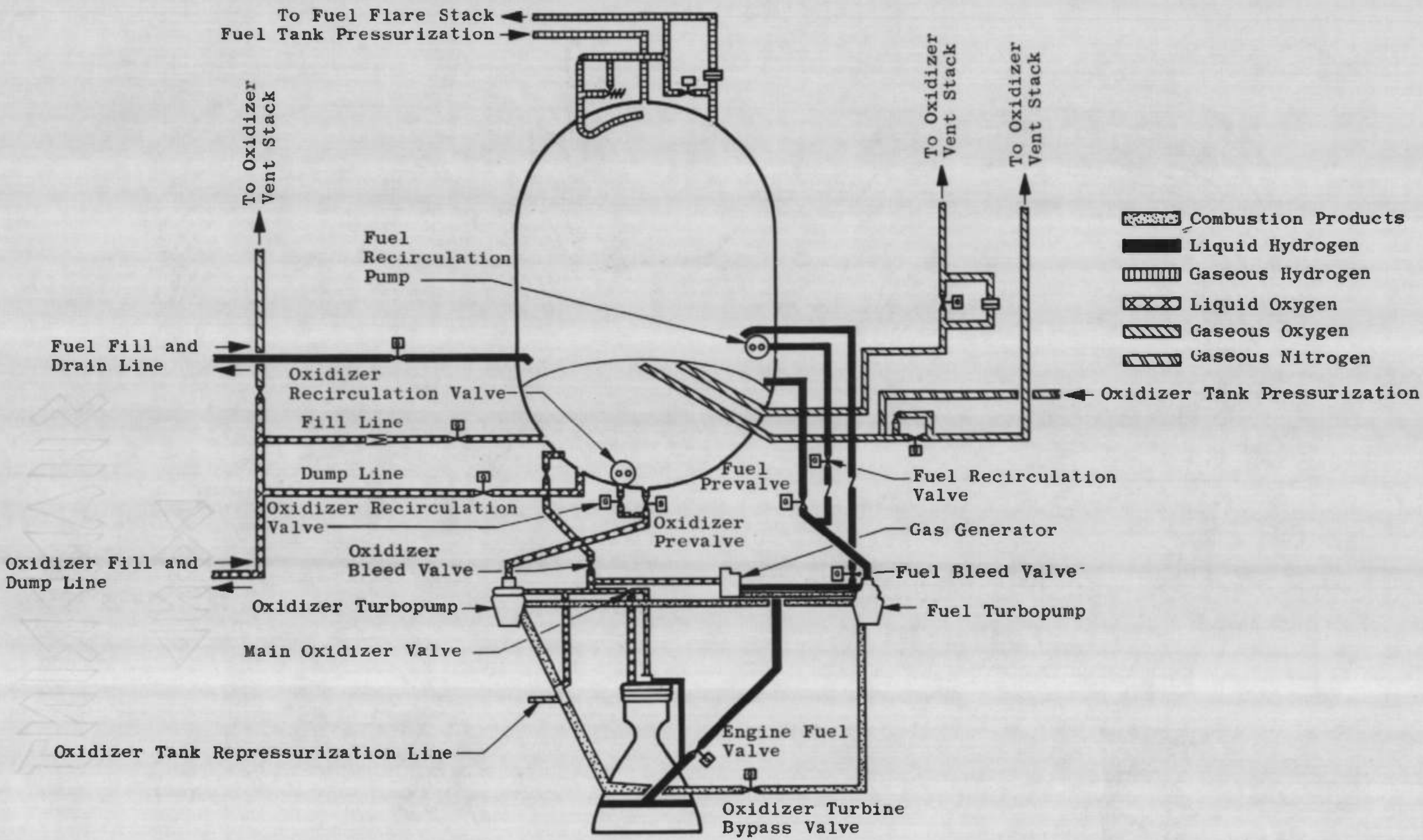


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

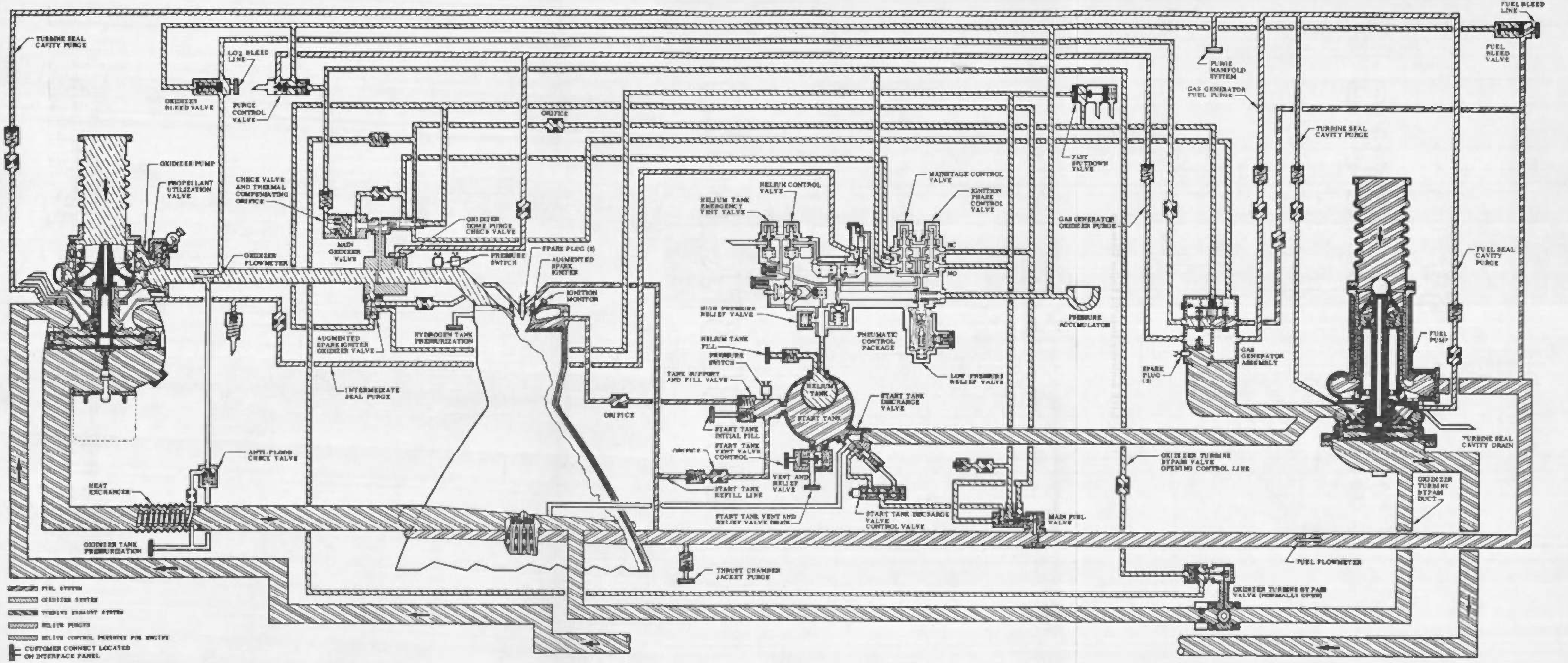


Fig. 5 Engine Schematic

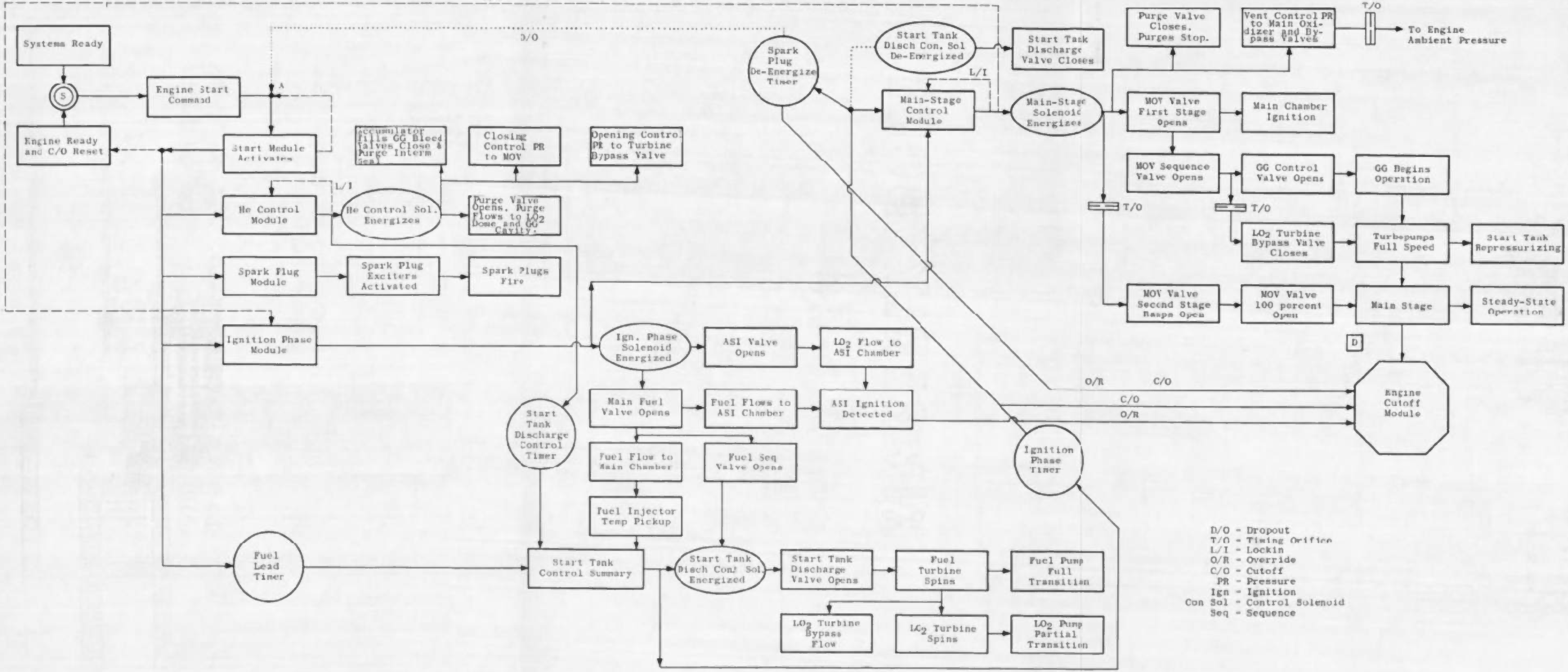
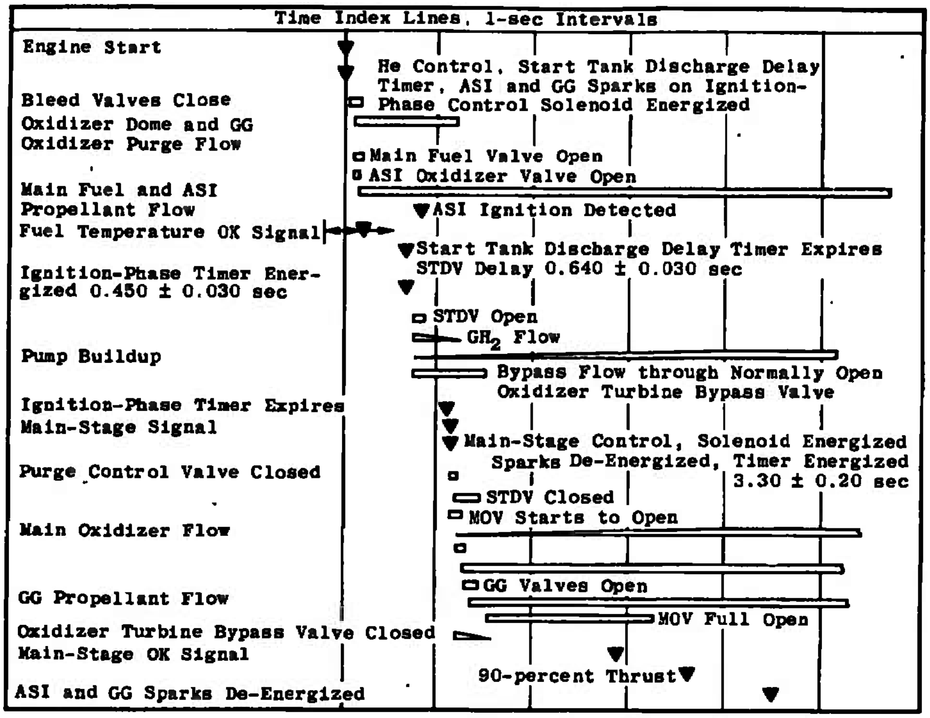
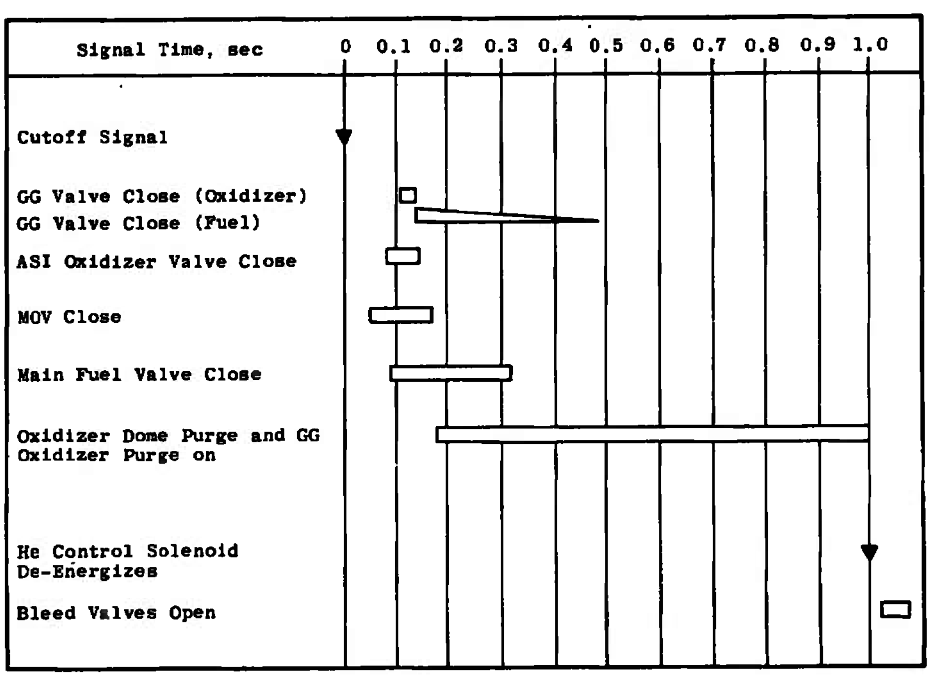


Fig. 6 Engine Start Logic Schematic

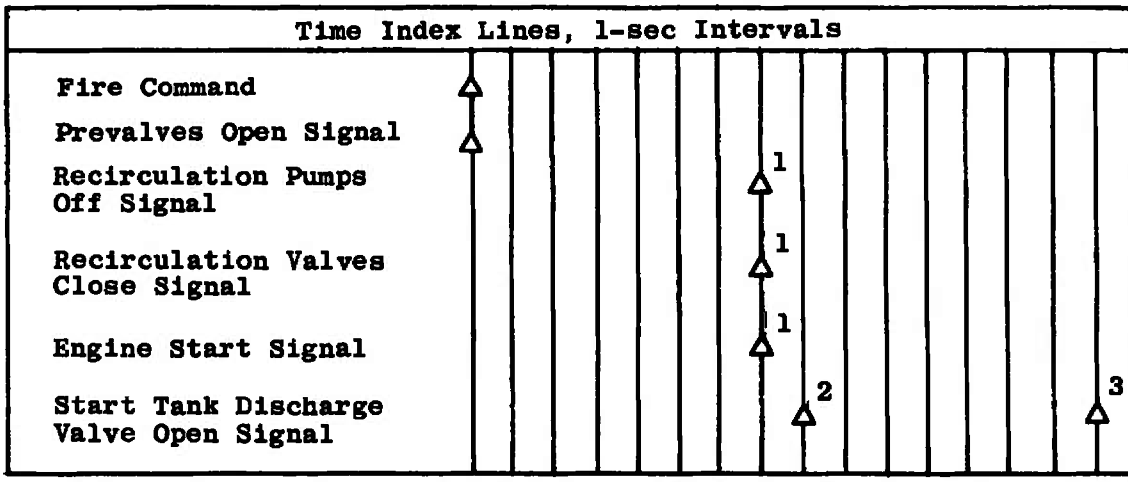


a. Start Sequence



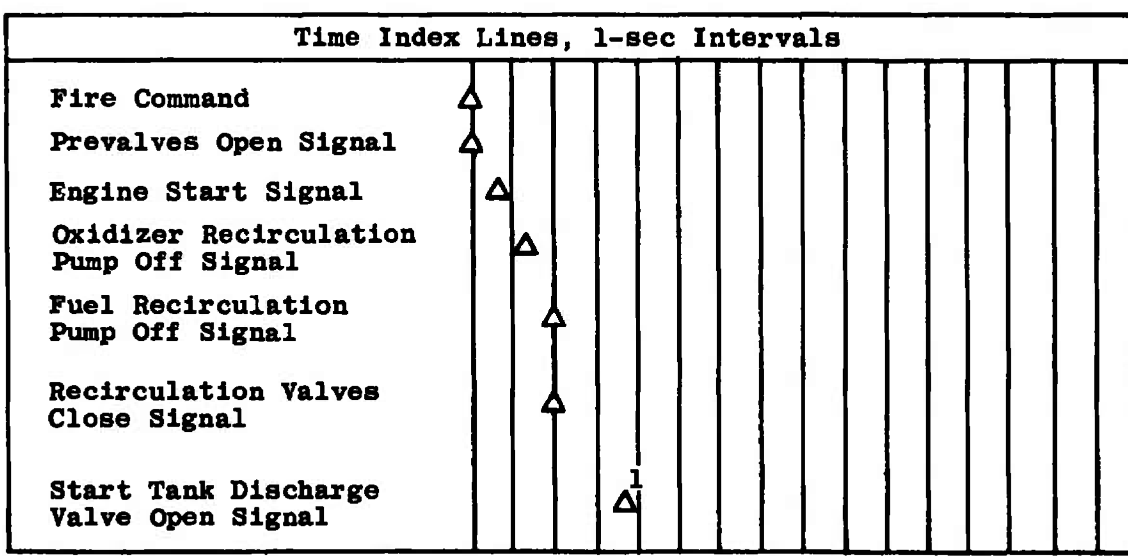
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1] Nominal Occurrence Time (Function of Prevalves Opening Time)
[2] One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3] Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

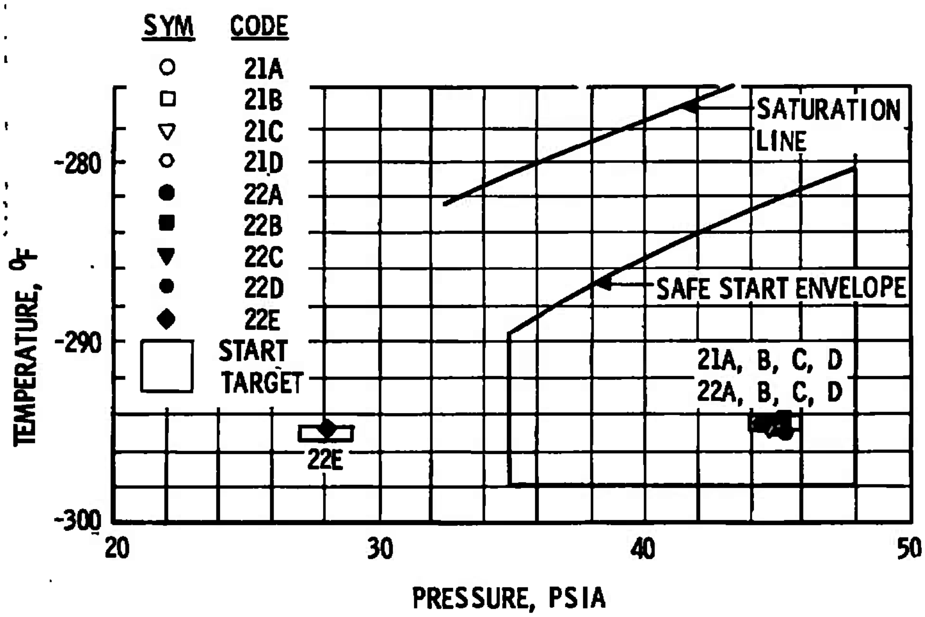
c. "Normal" Start Sequence



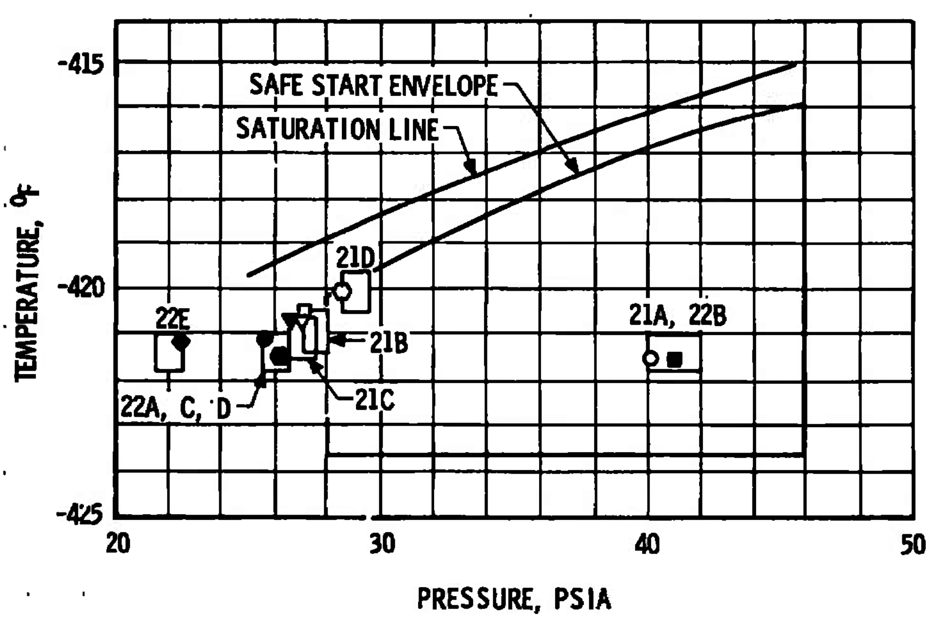
[1] Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

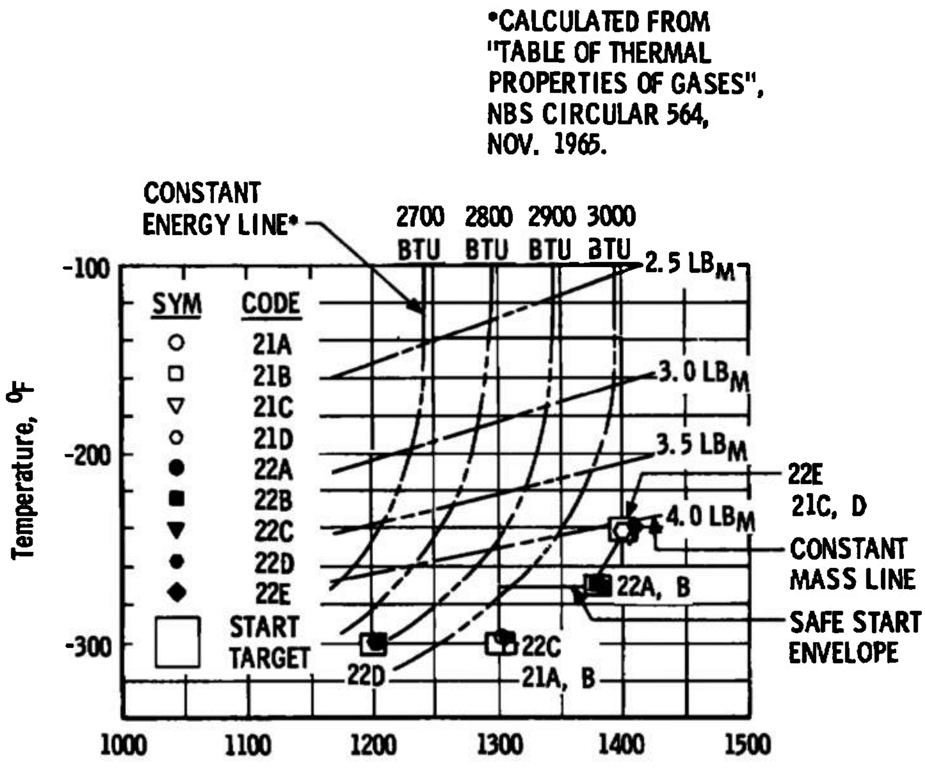


a. Oxidizer Pump Inlet

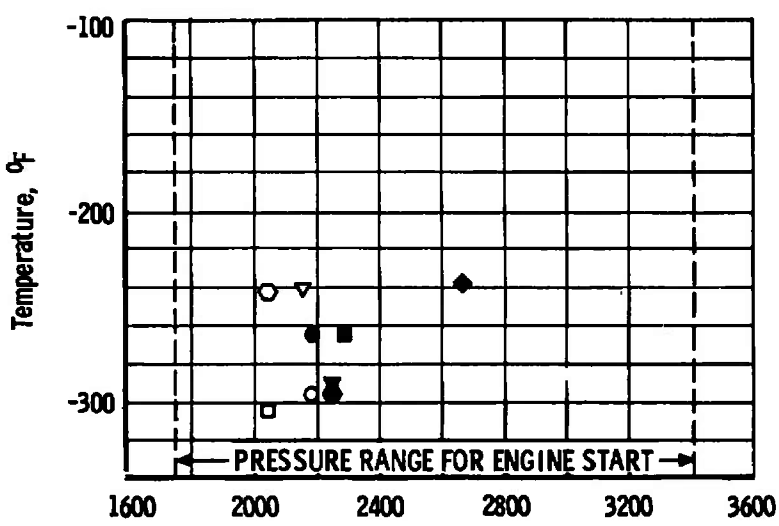


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

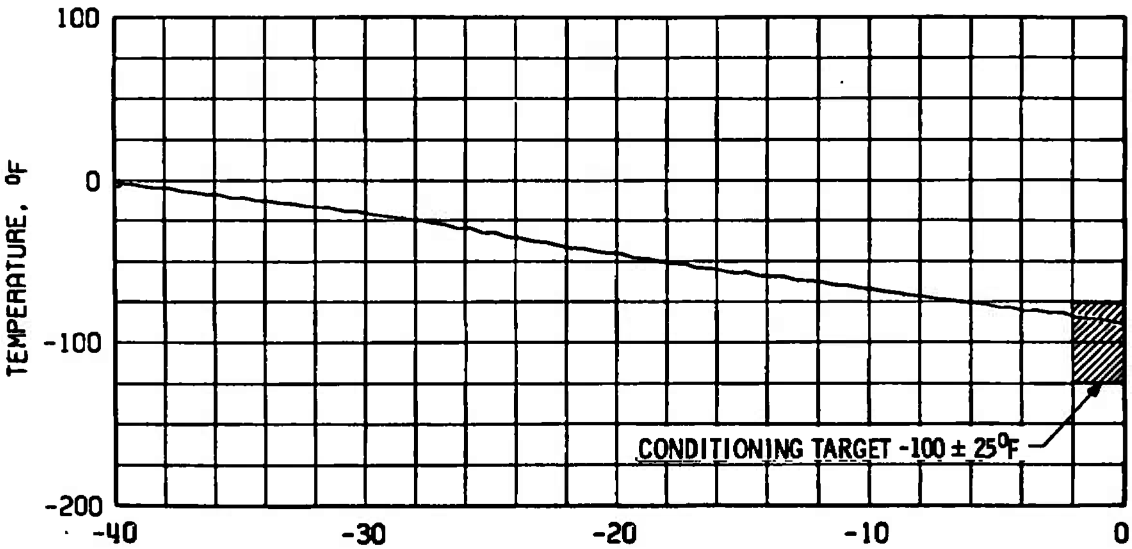


c. Start Tank

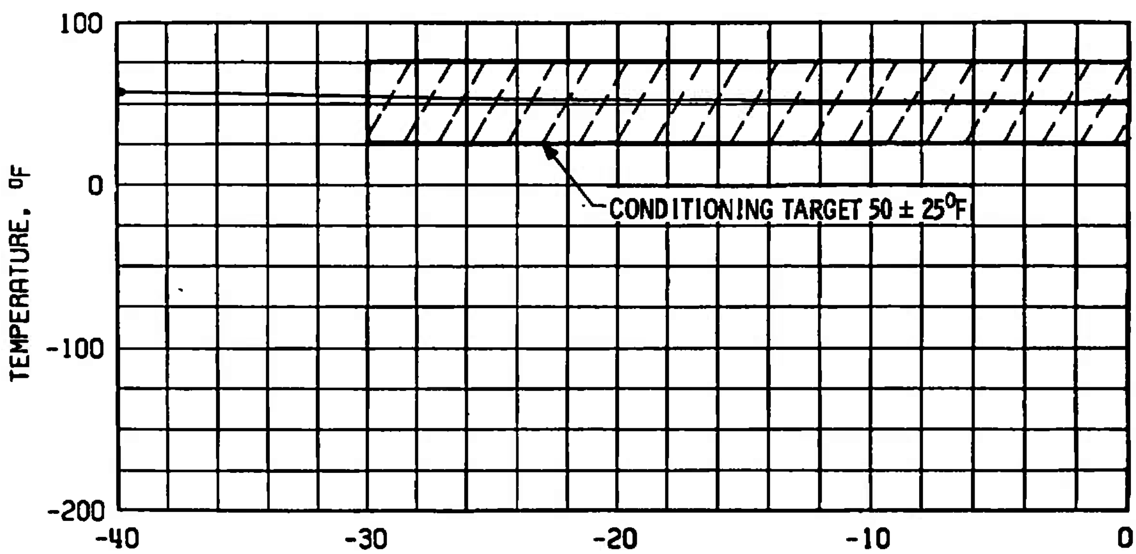


d. Helium Tank

Fig. 8 Concluded

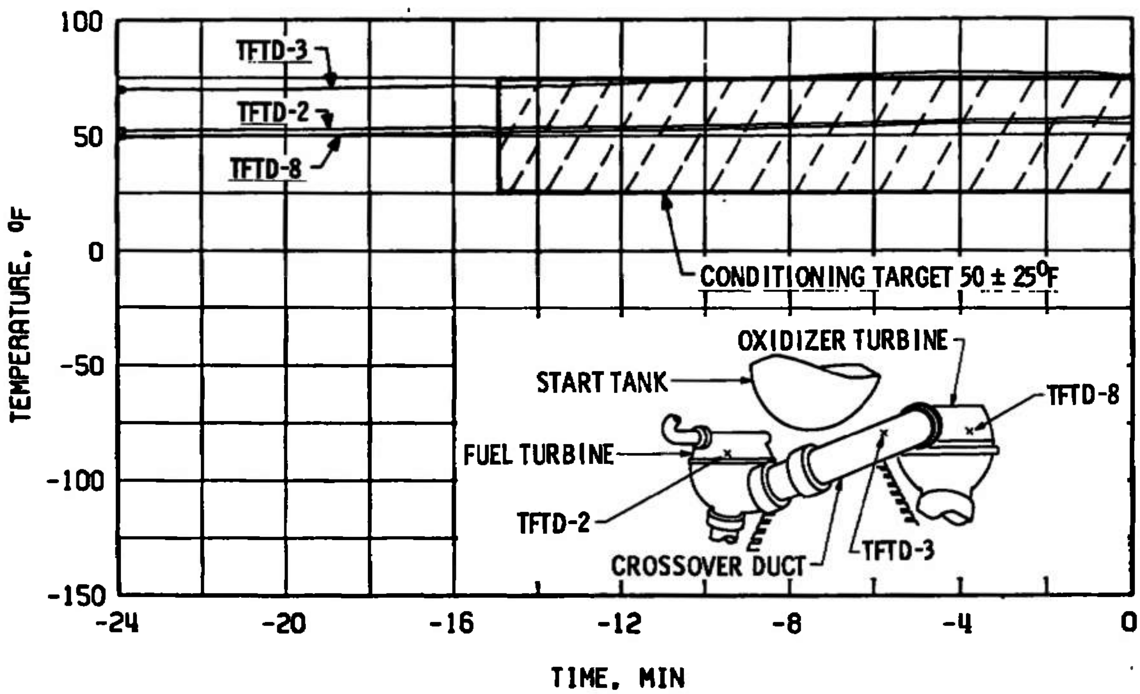


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

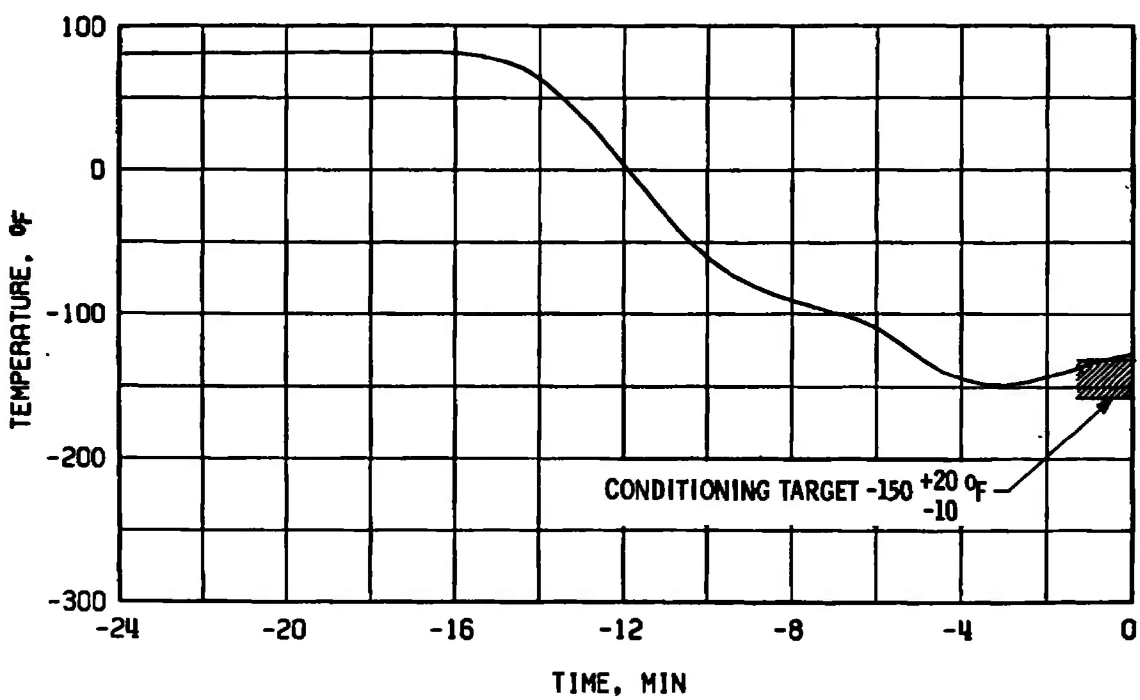


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 9 History of Firing 21A Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD



d. Thrust Chamber Temperature, TTC-1P

Fig. 9 Concluded

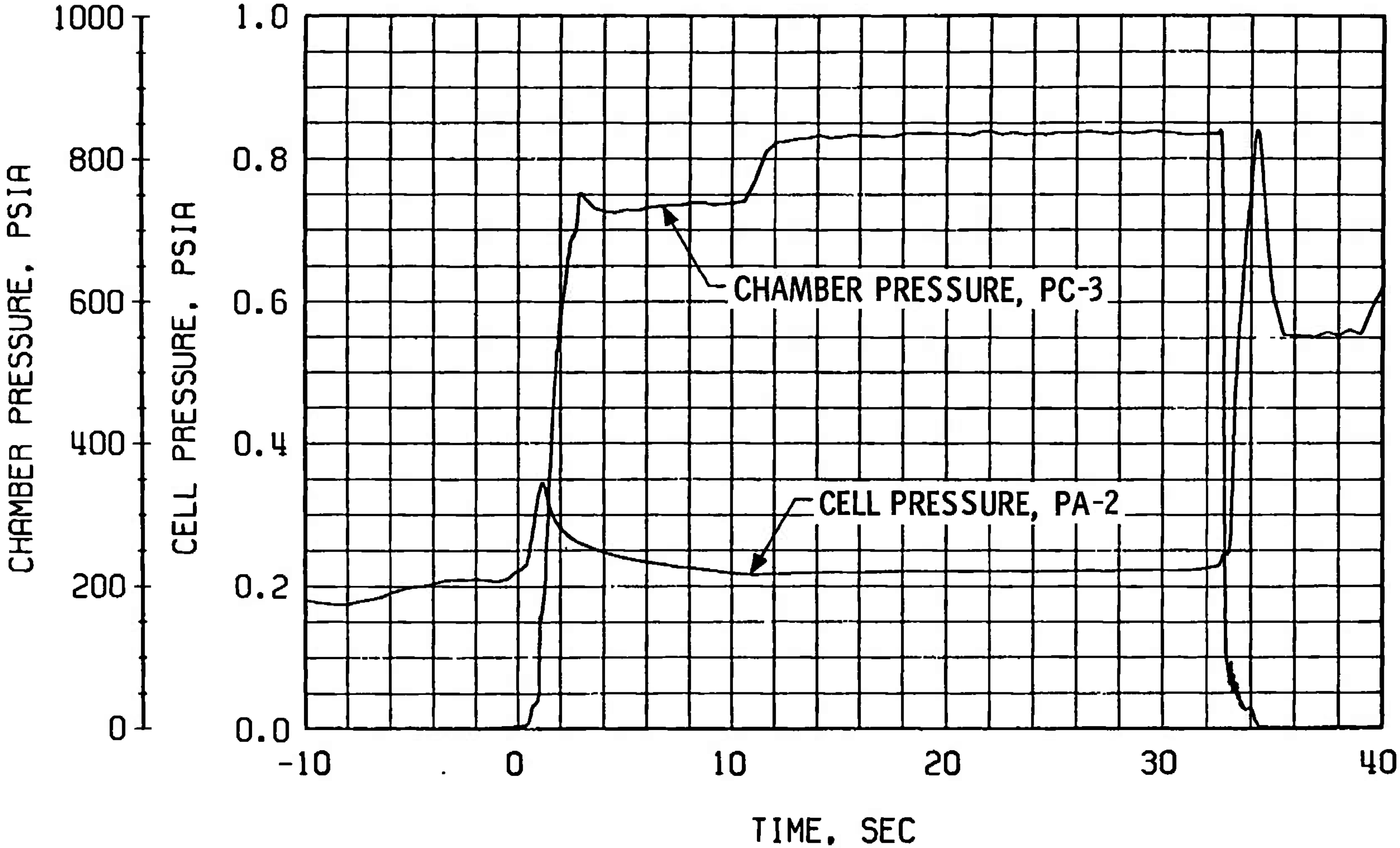
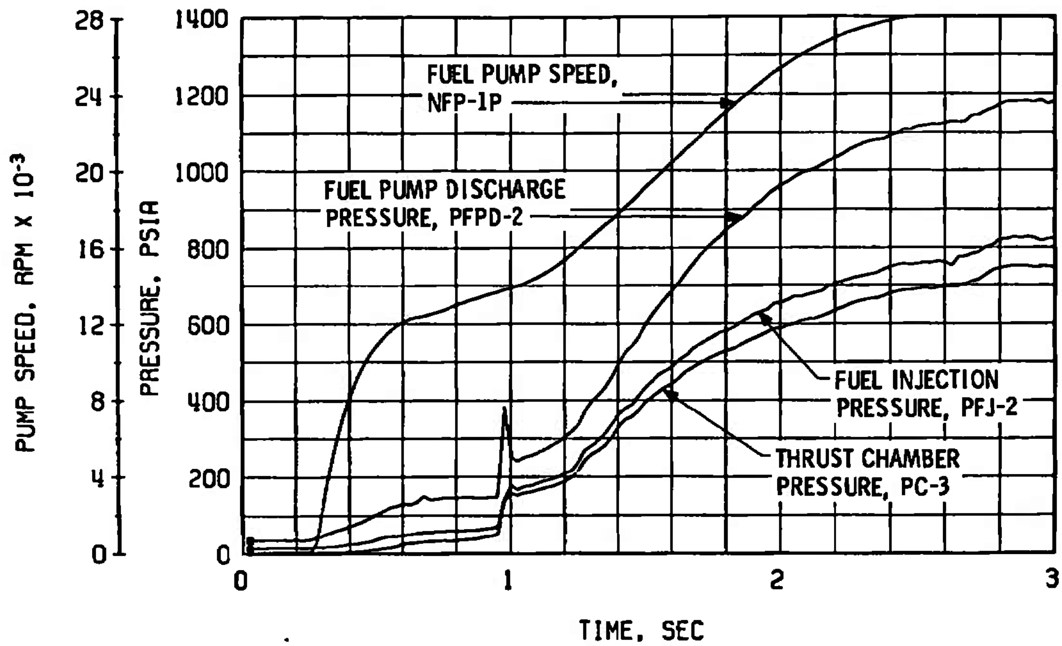
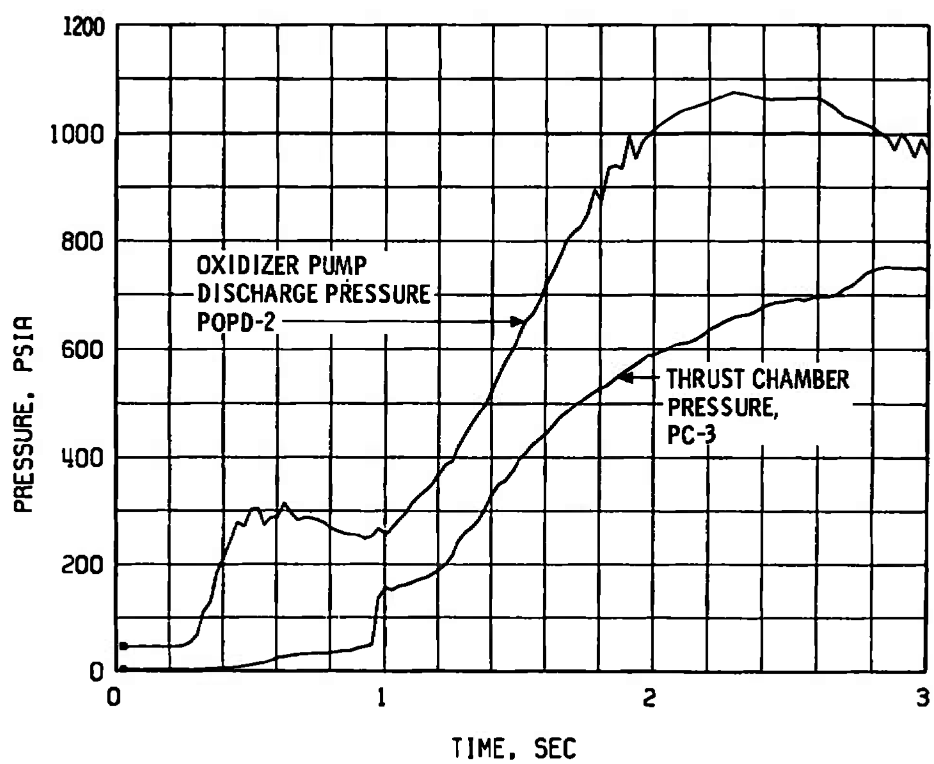


Fig. 10 Engine Chamber and Test Capsule Pressures, Firing 21A

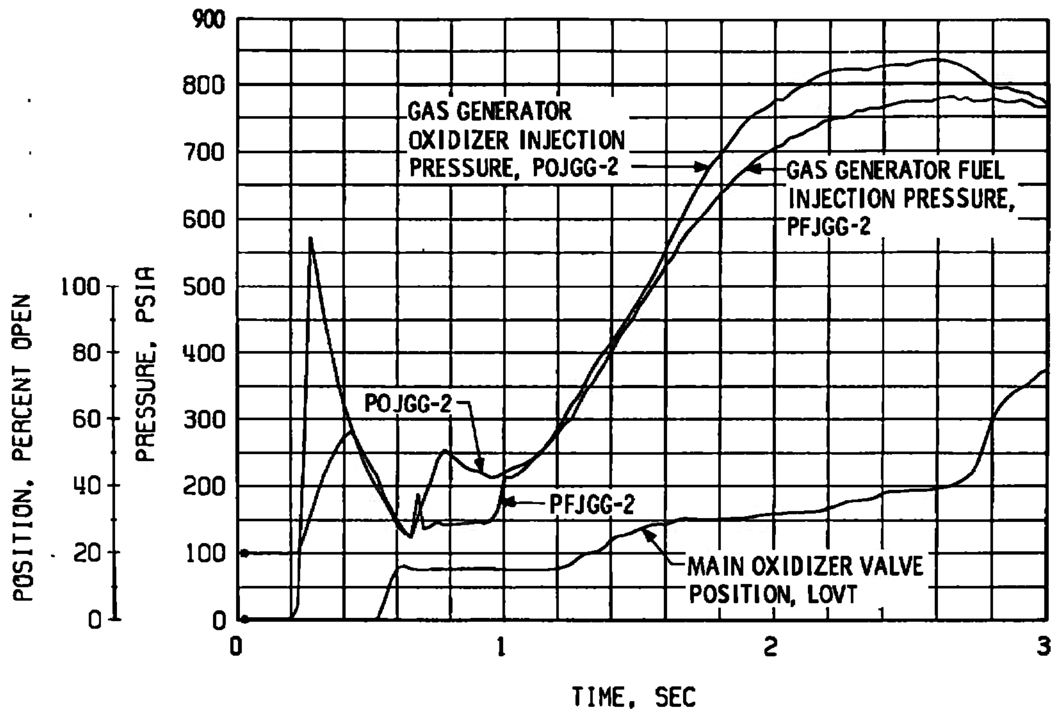


a. Start Transient, Thrust Chamber Fuel System

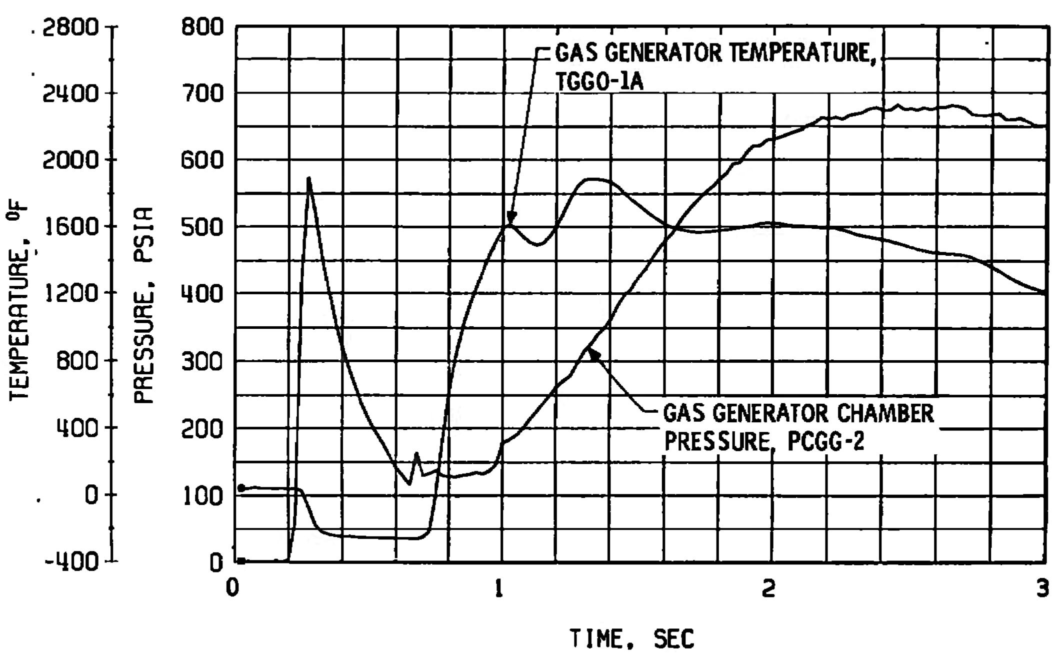


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 11 Engine Start and Shutdown Transients, Firing 21A

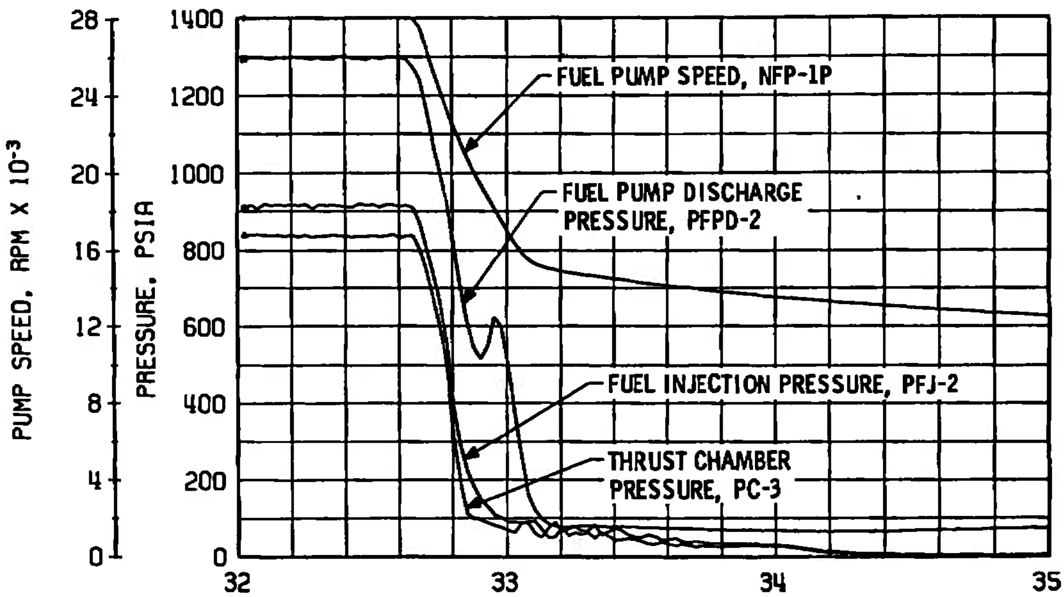


c. Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position

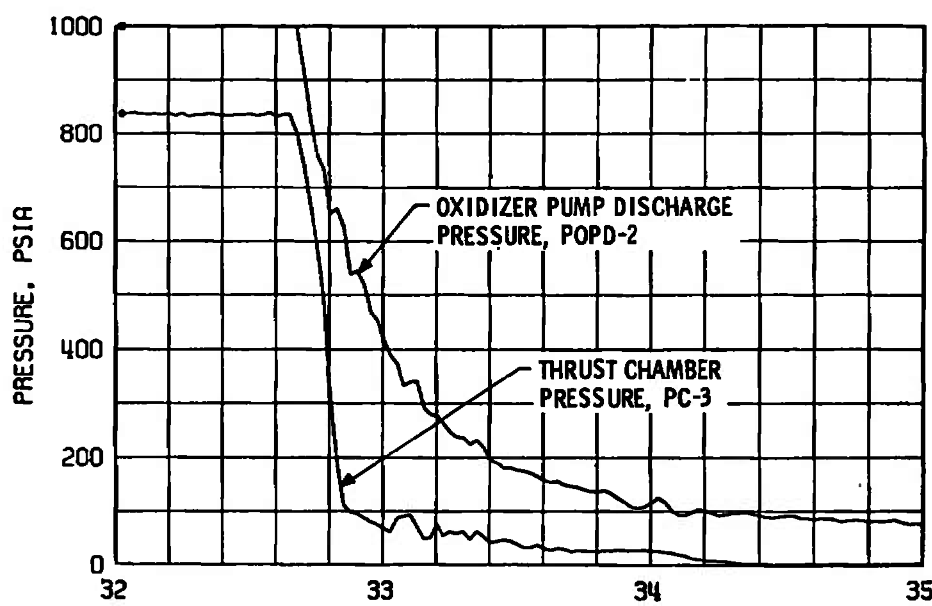


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 11 Continued

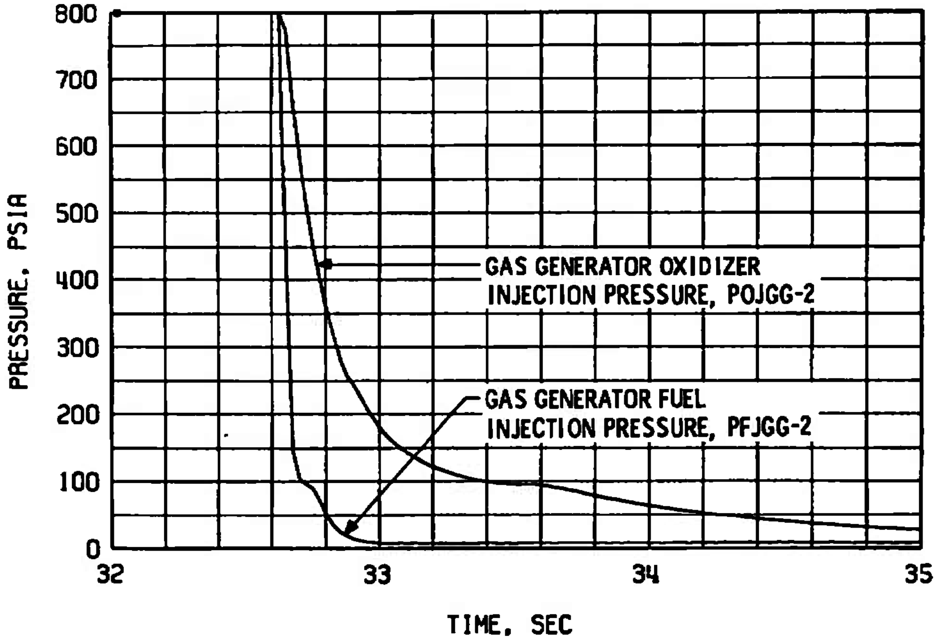


e. Shutdown Transient, Thrust Chamber Fuel System

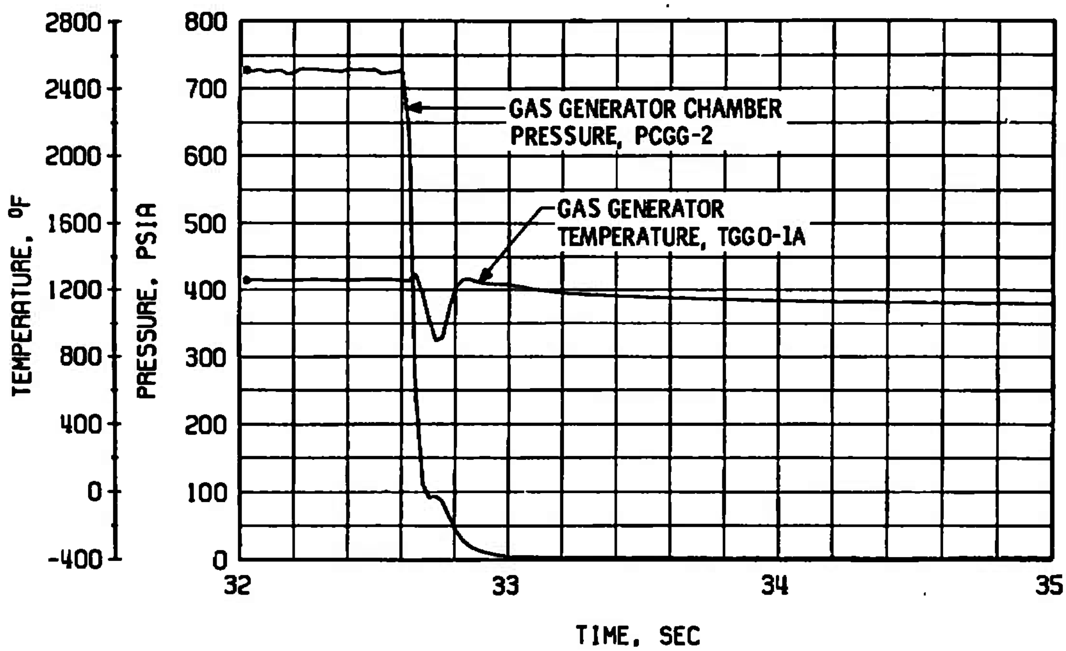


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 11 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 11 Concluded

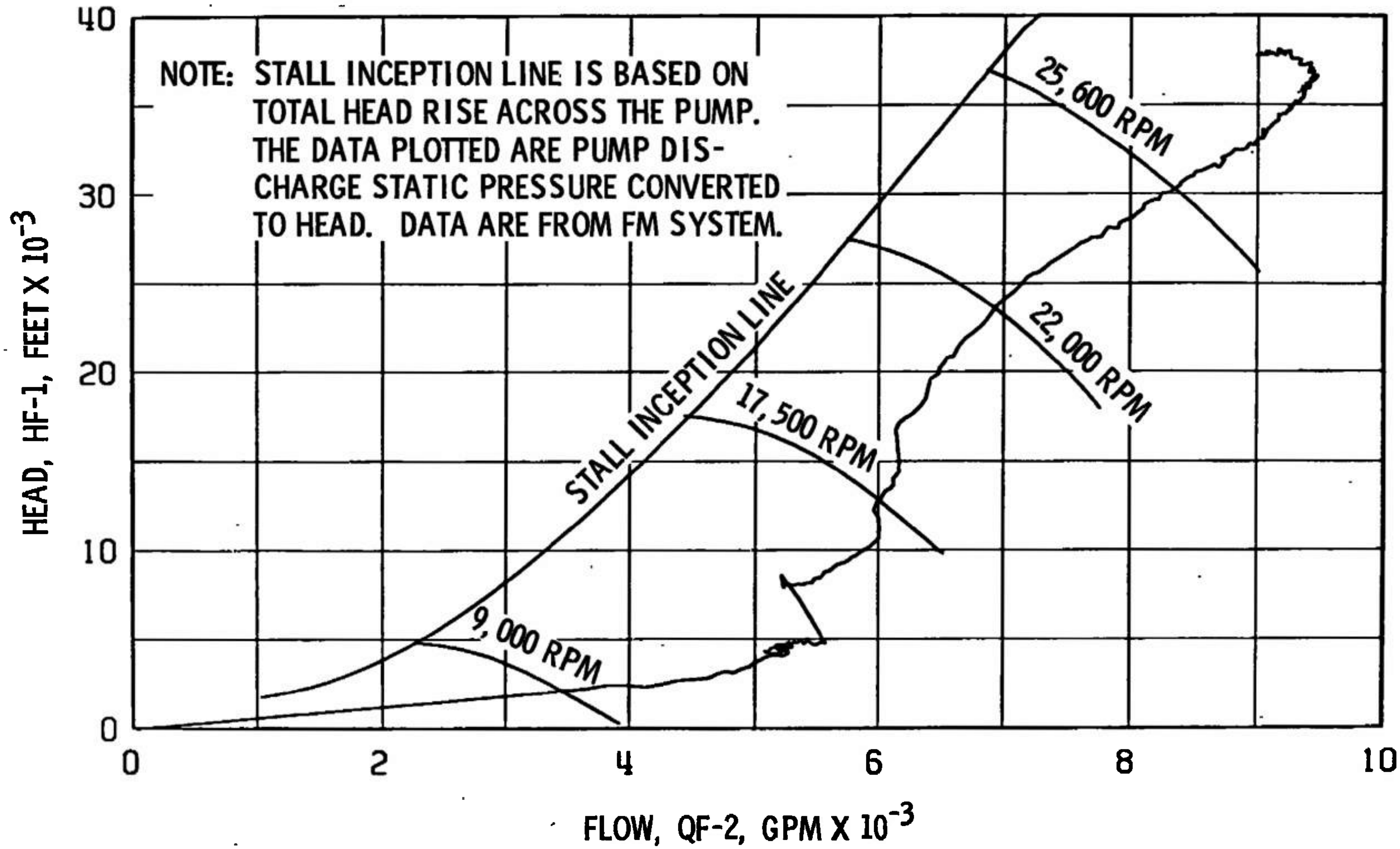
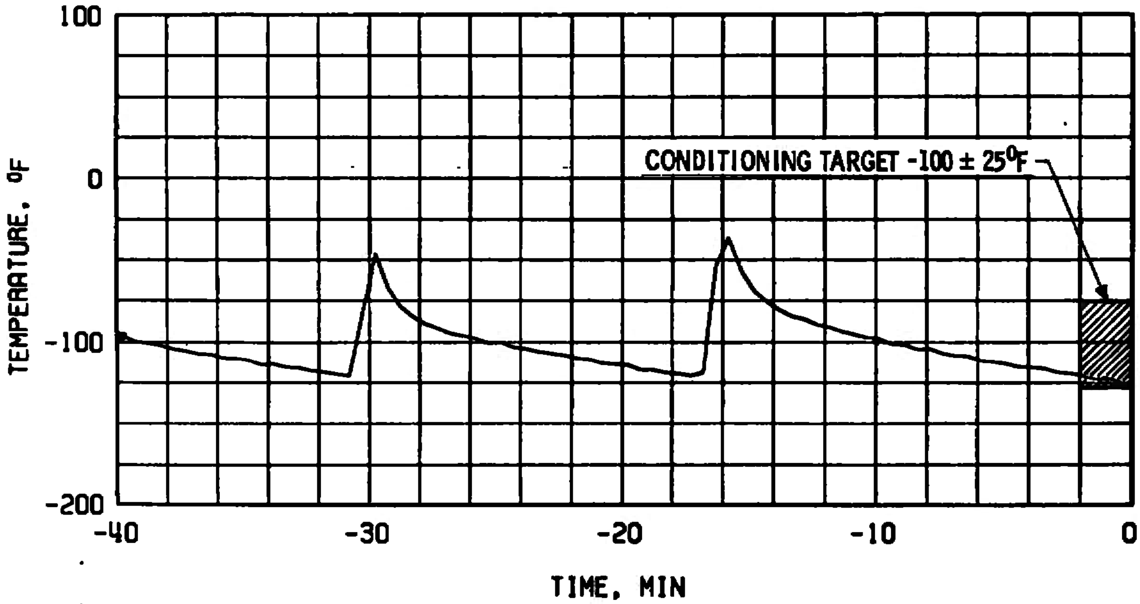
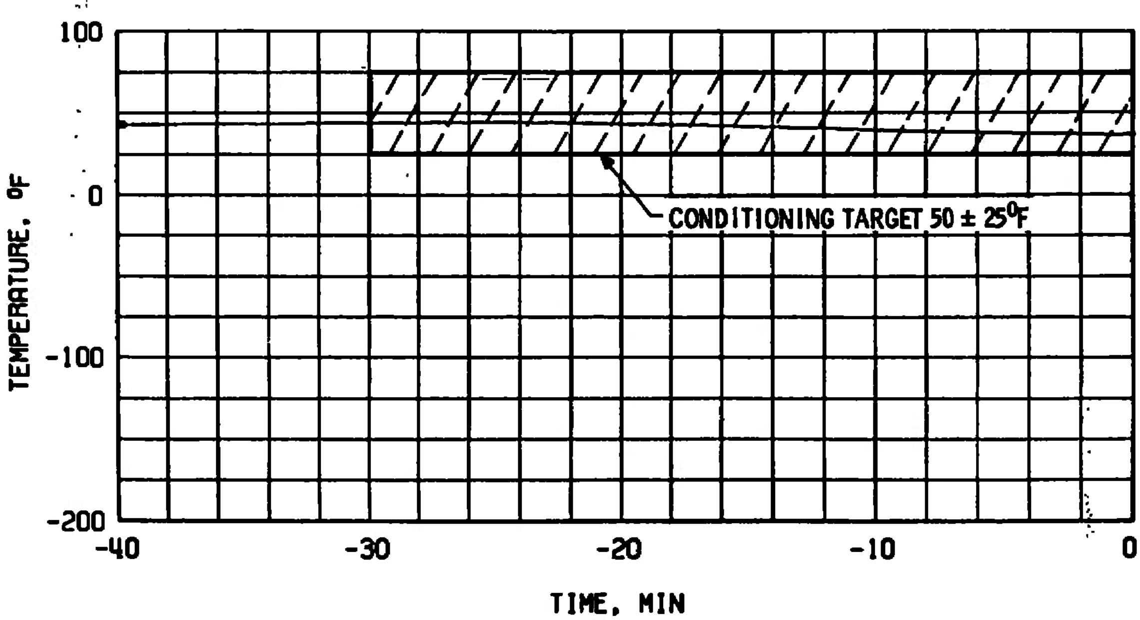


Fig. 12 Fuel Pump Transient Performance, Firing 21A

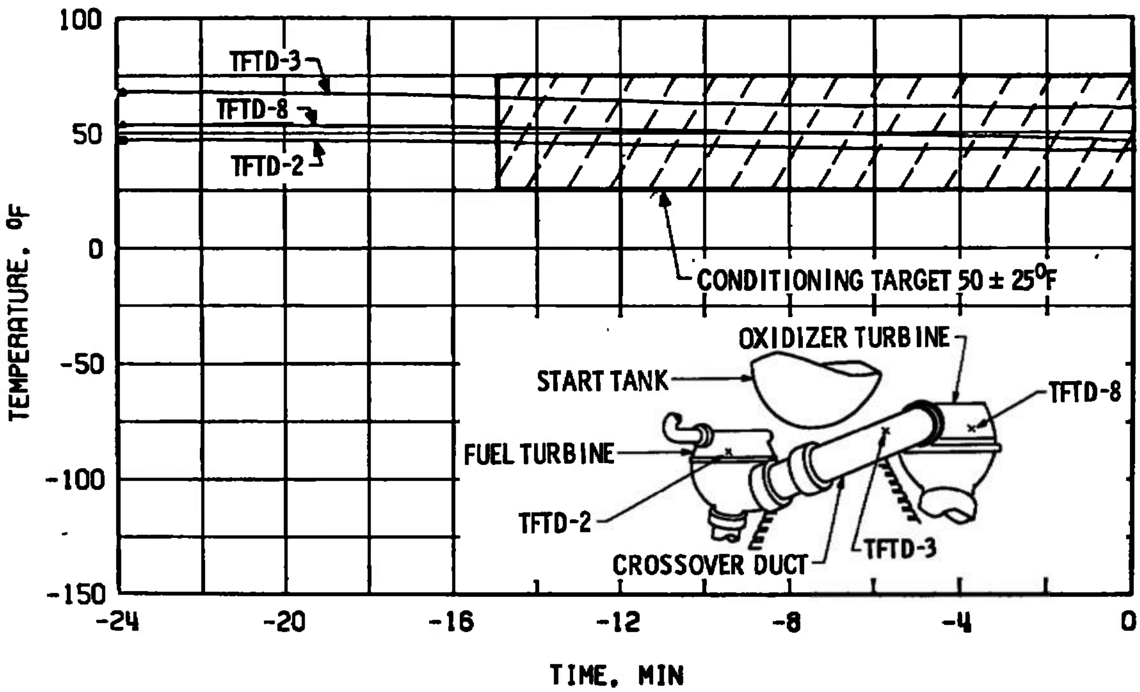


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

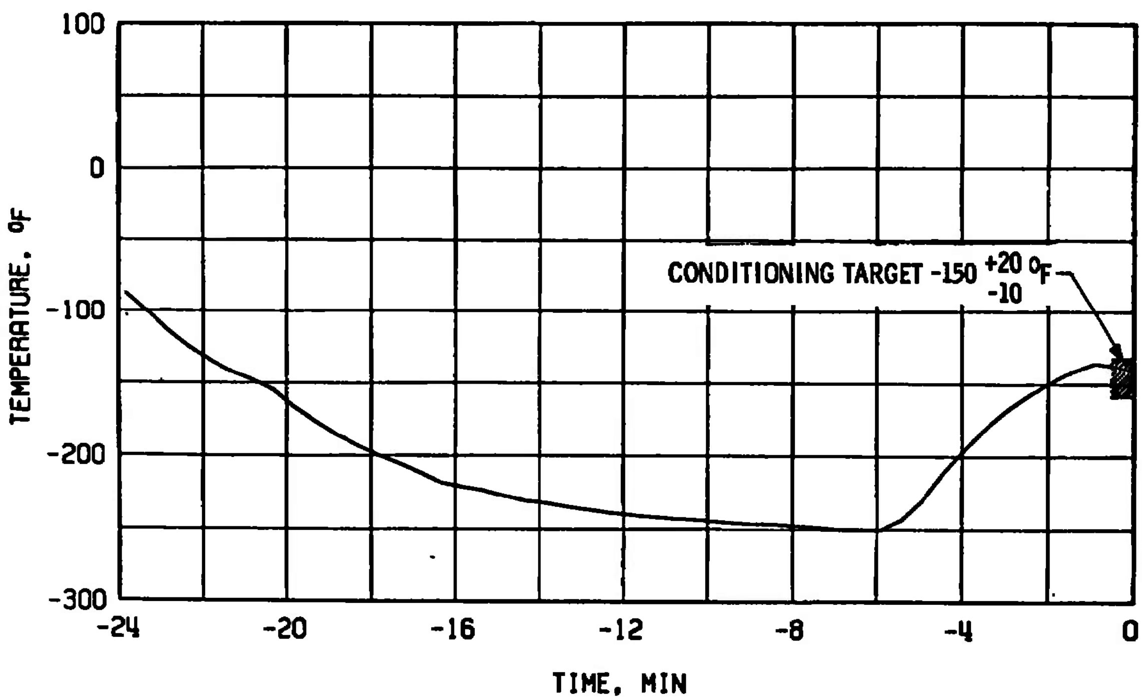


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 13 History of Firing 21B Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3, and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 13 Concluded

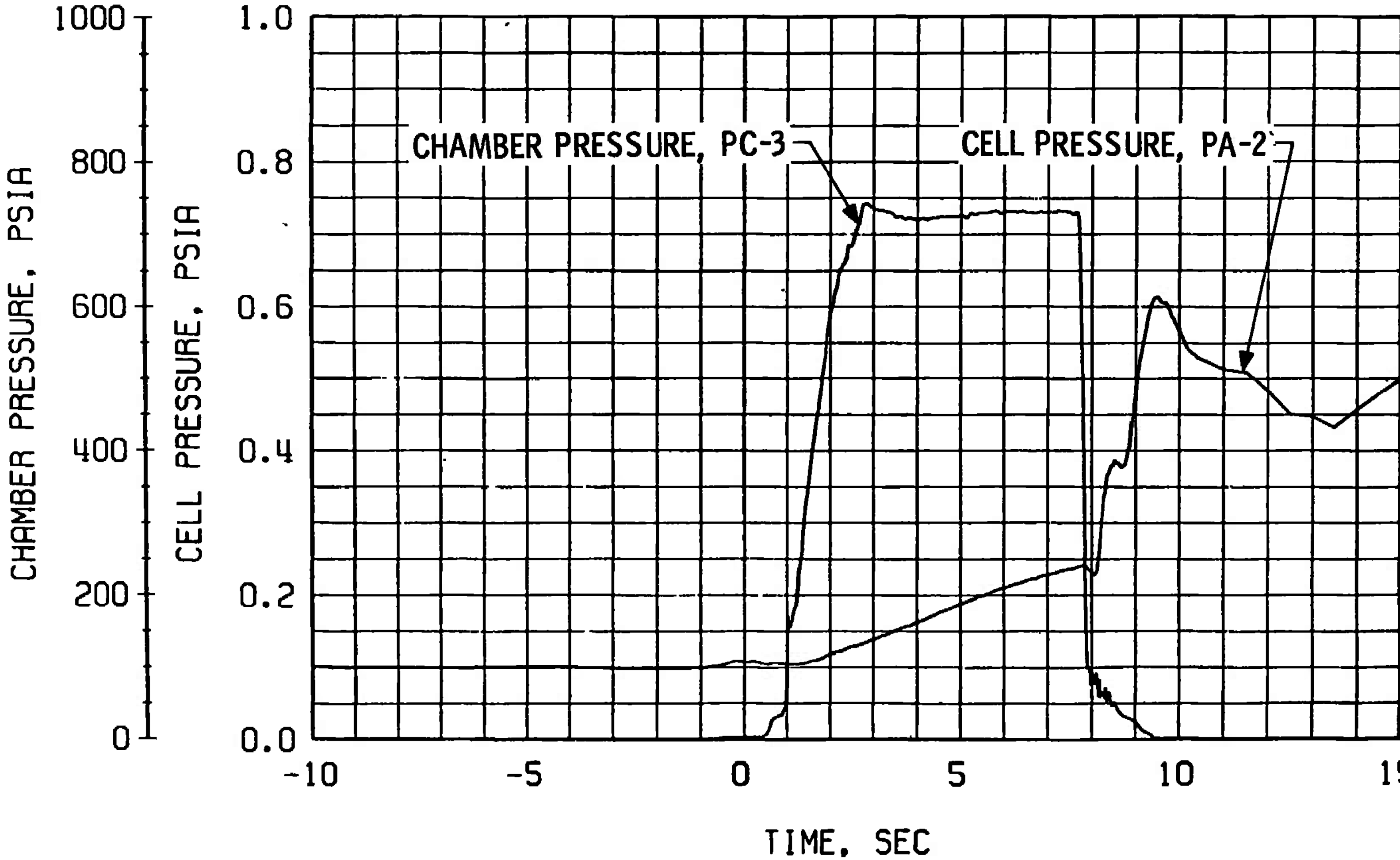
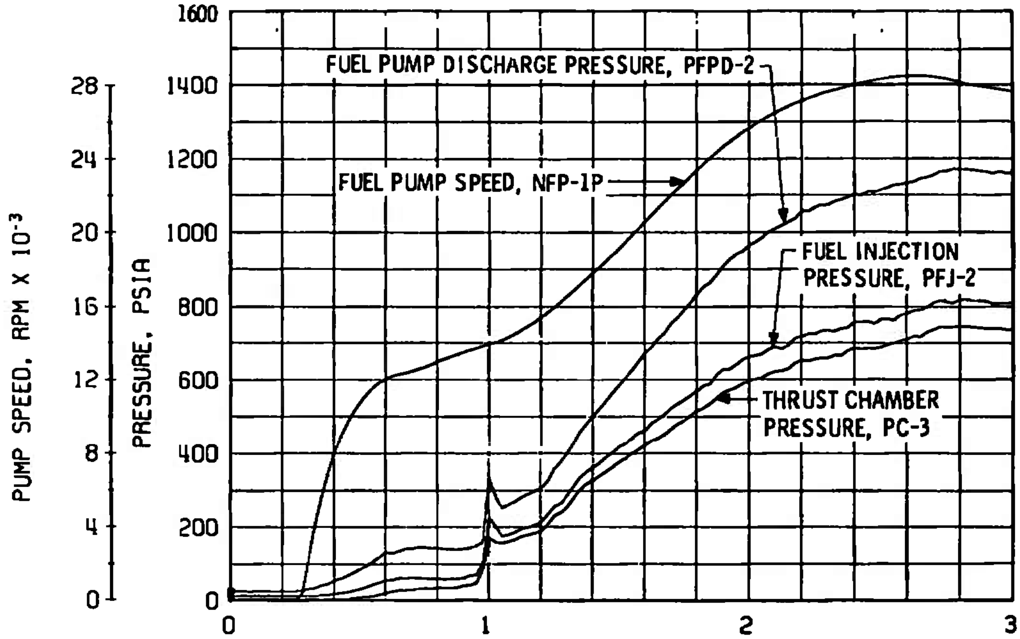
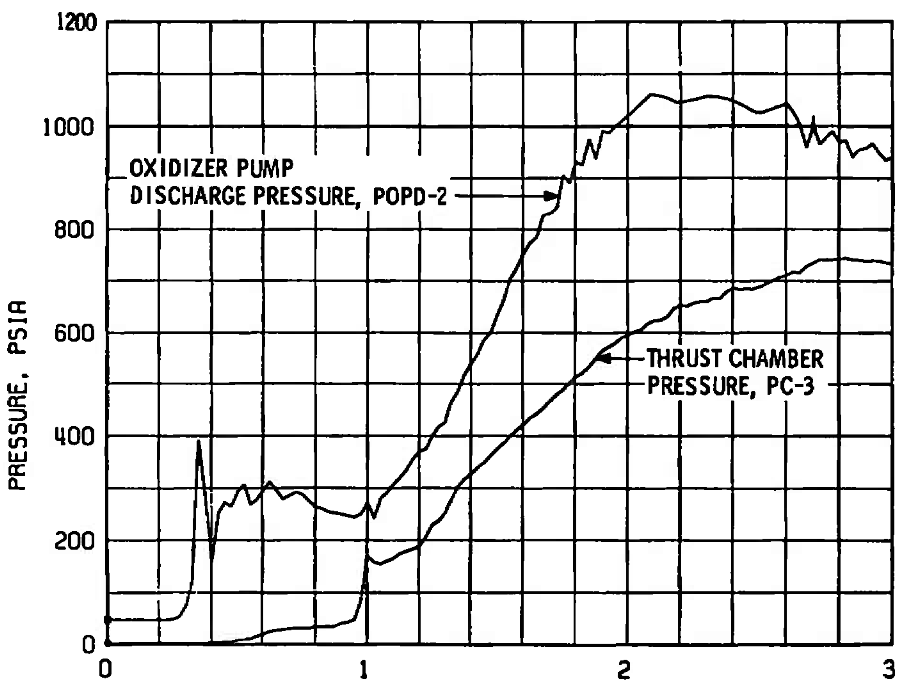


Fig. 14 Engine Chamber and Test Capsule Pressure, Firing 21B

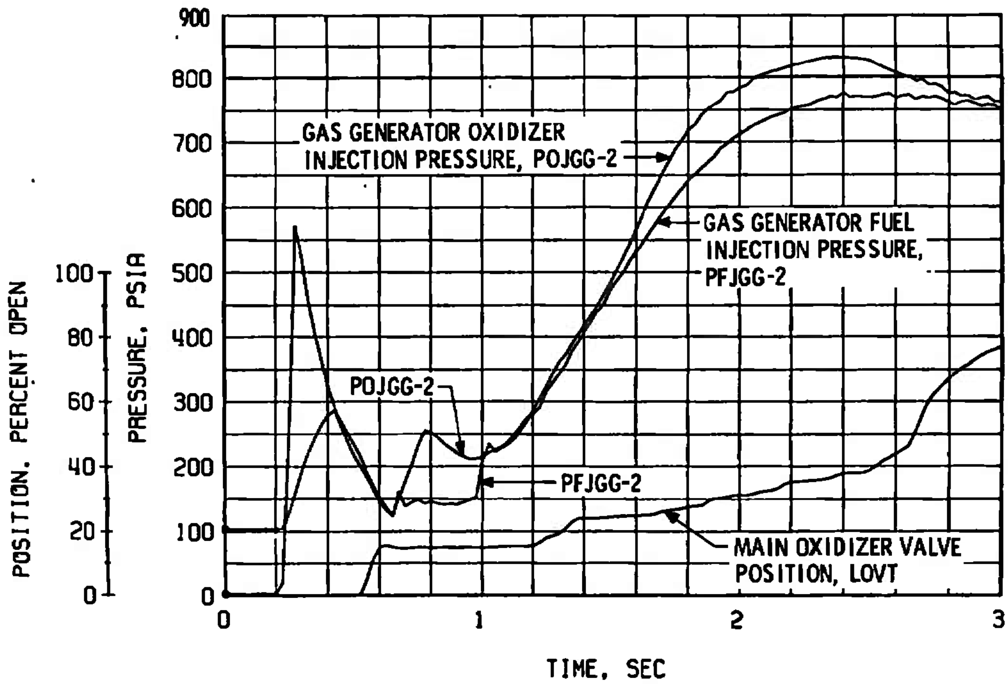


a. Start Transient, Thrust Chamber Fuel System

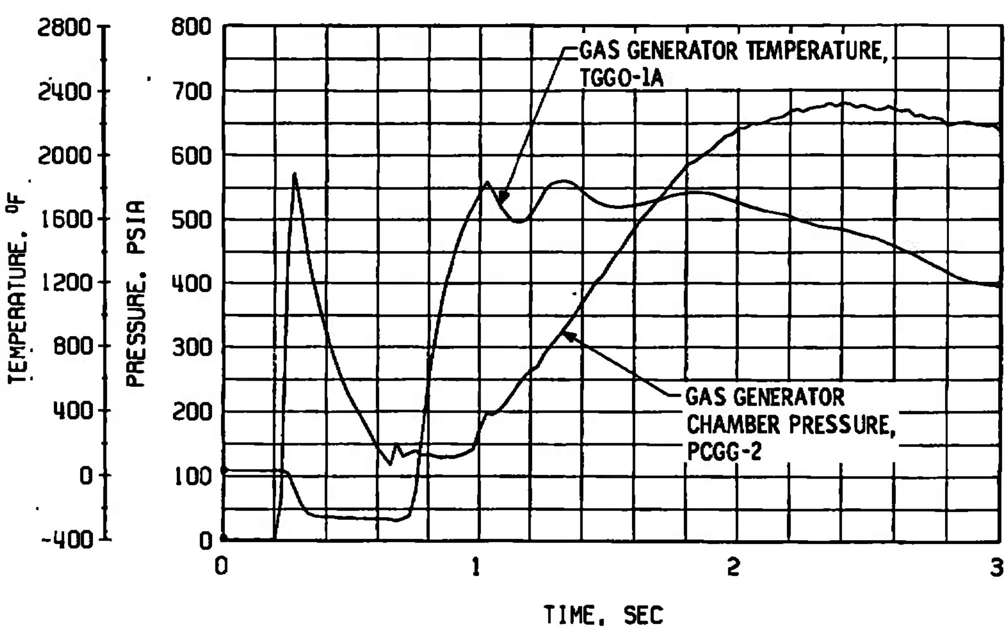


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 15 Engine Start and Shutdown Transients, Firing 21B

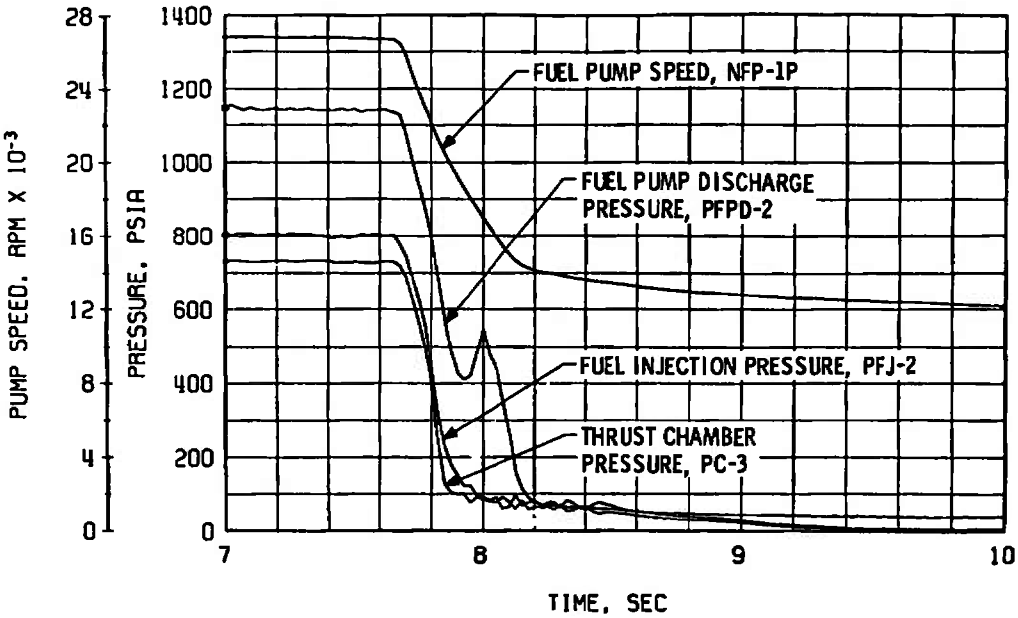


c. Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position

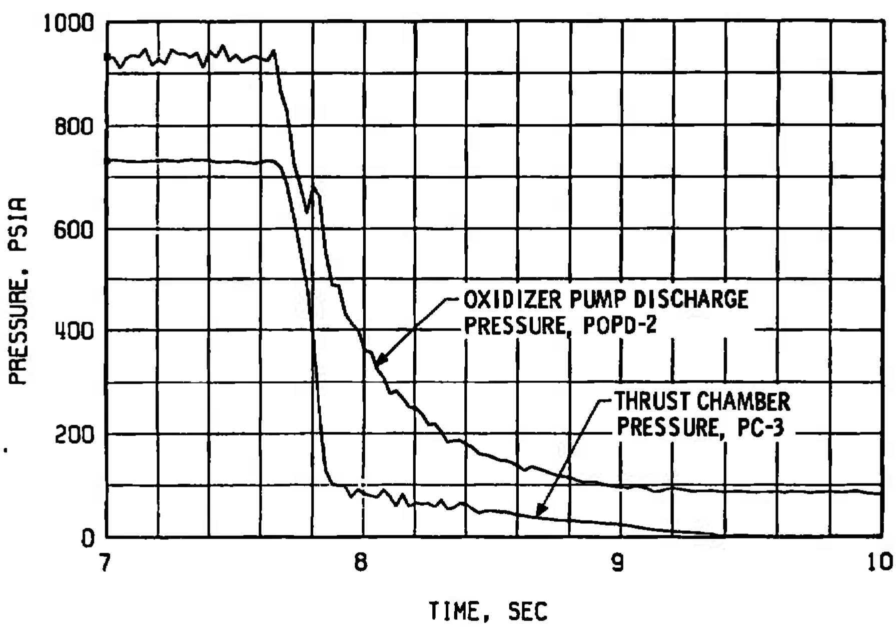


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 15 Continued

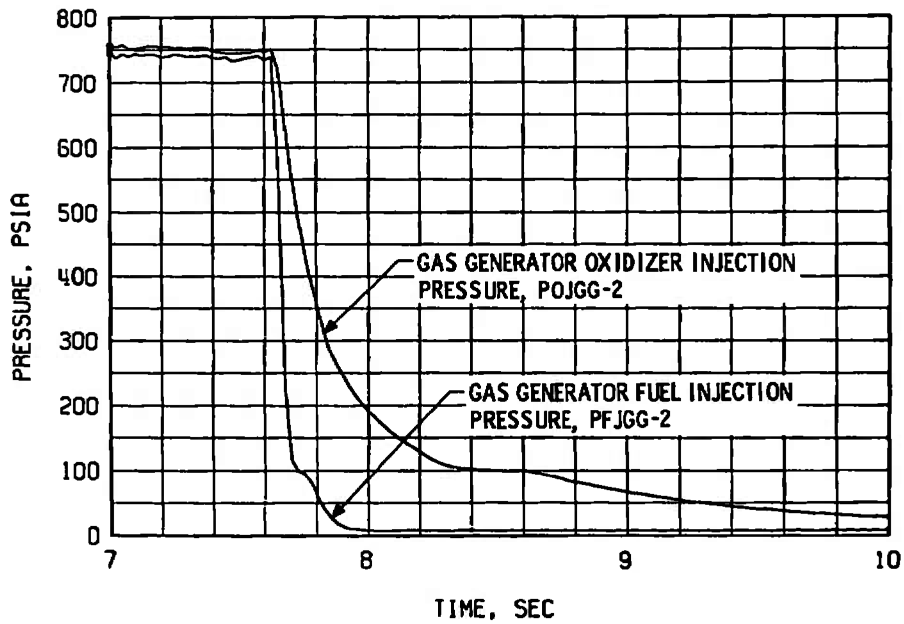


e. Shutdown Transient, Thrust Chamber Fuel System

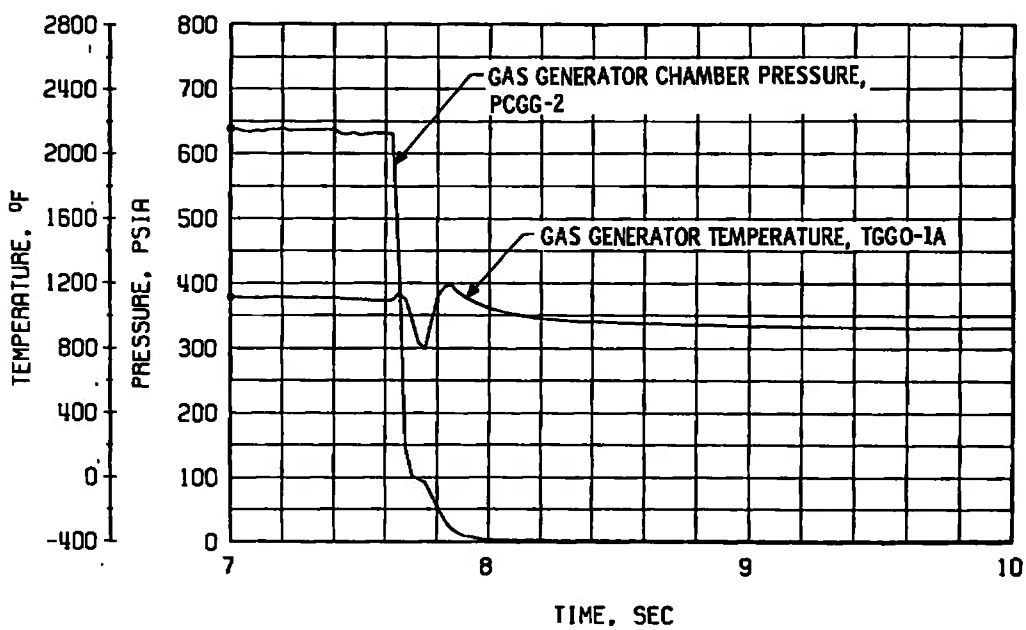


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 15 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 15 Concluded

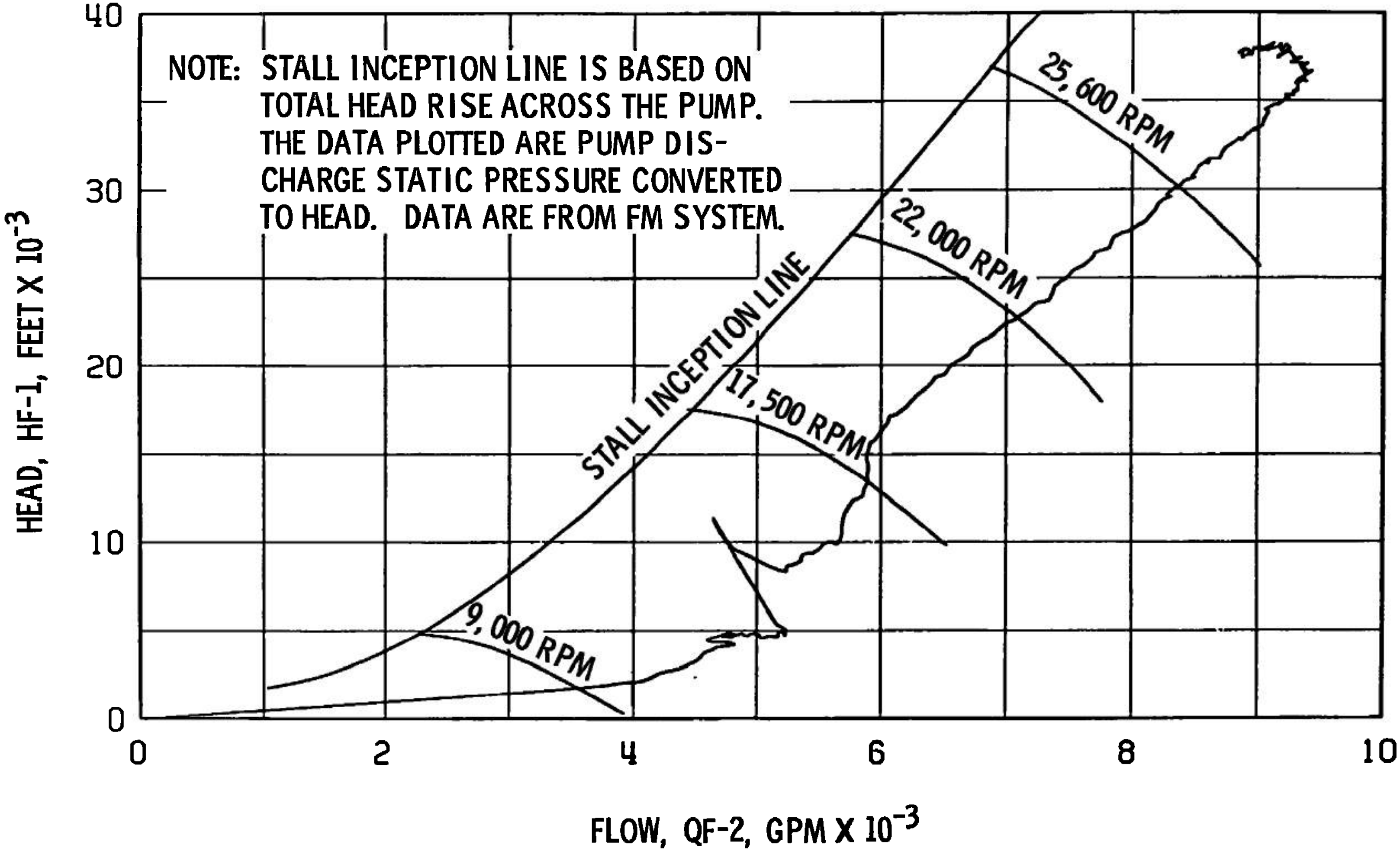
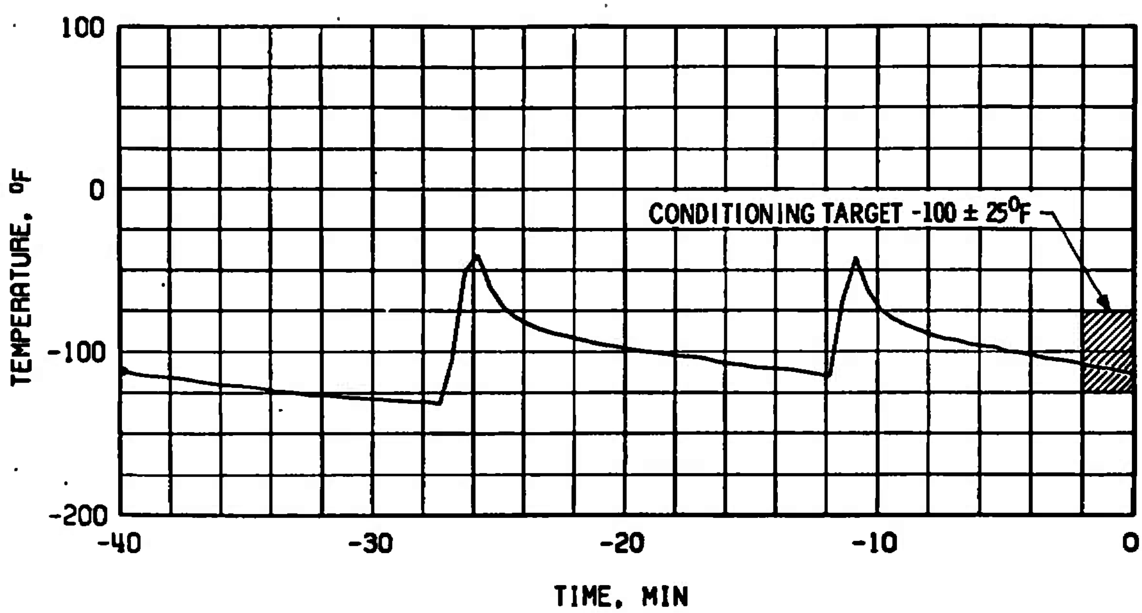
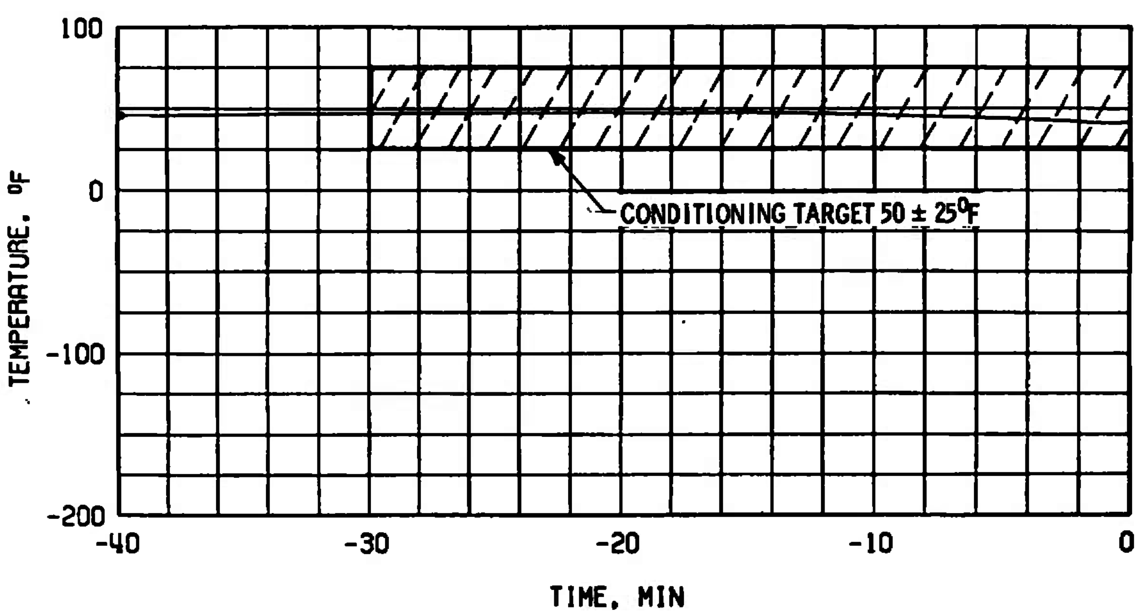


Fig. 16 Fuel Pump Transient Performance, Firing 21B

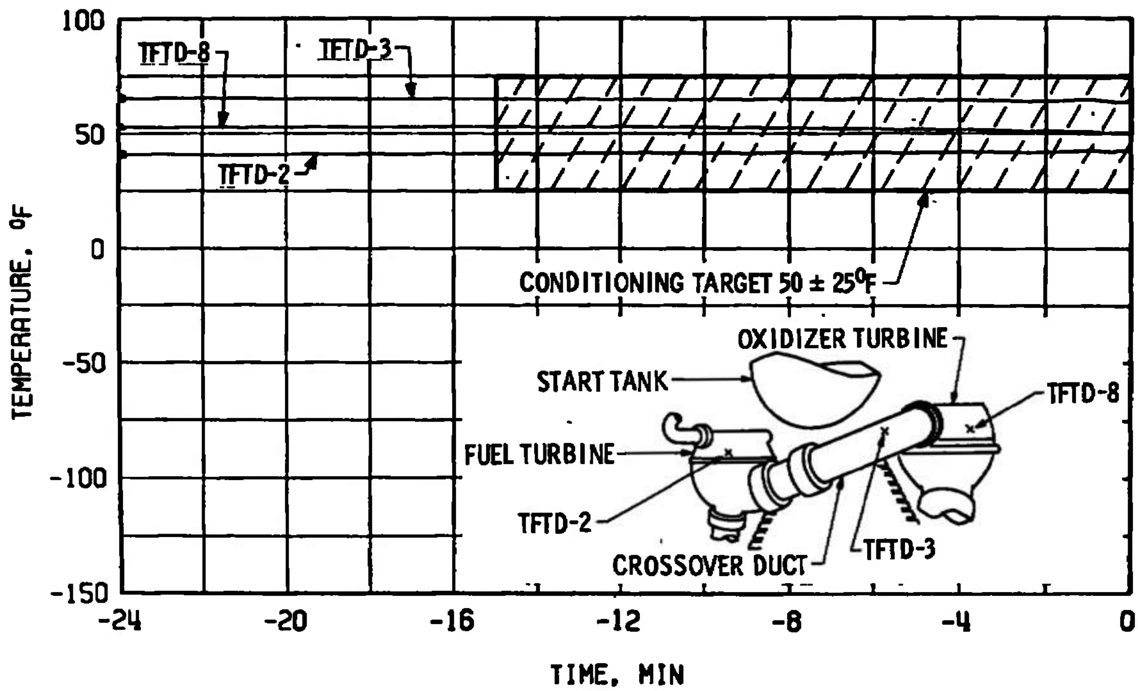


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

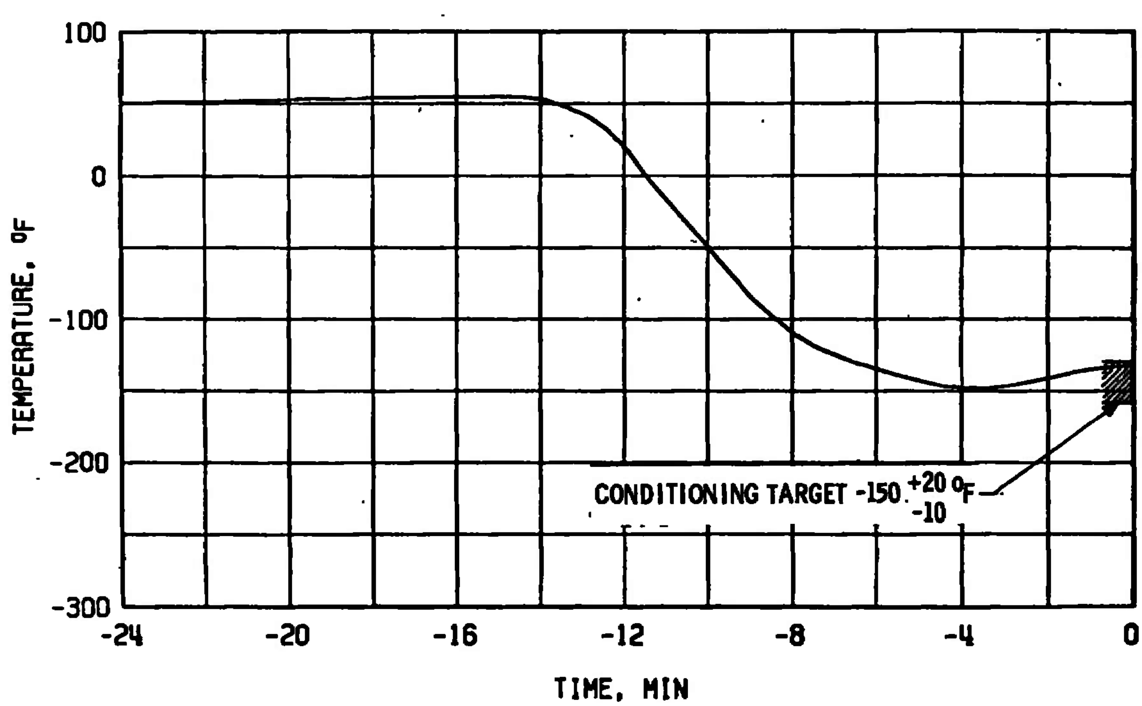


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 17 History of Firing 21C Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3, and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 17 Concluded

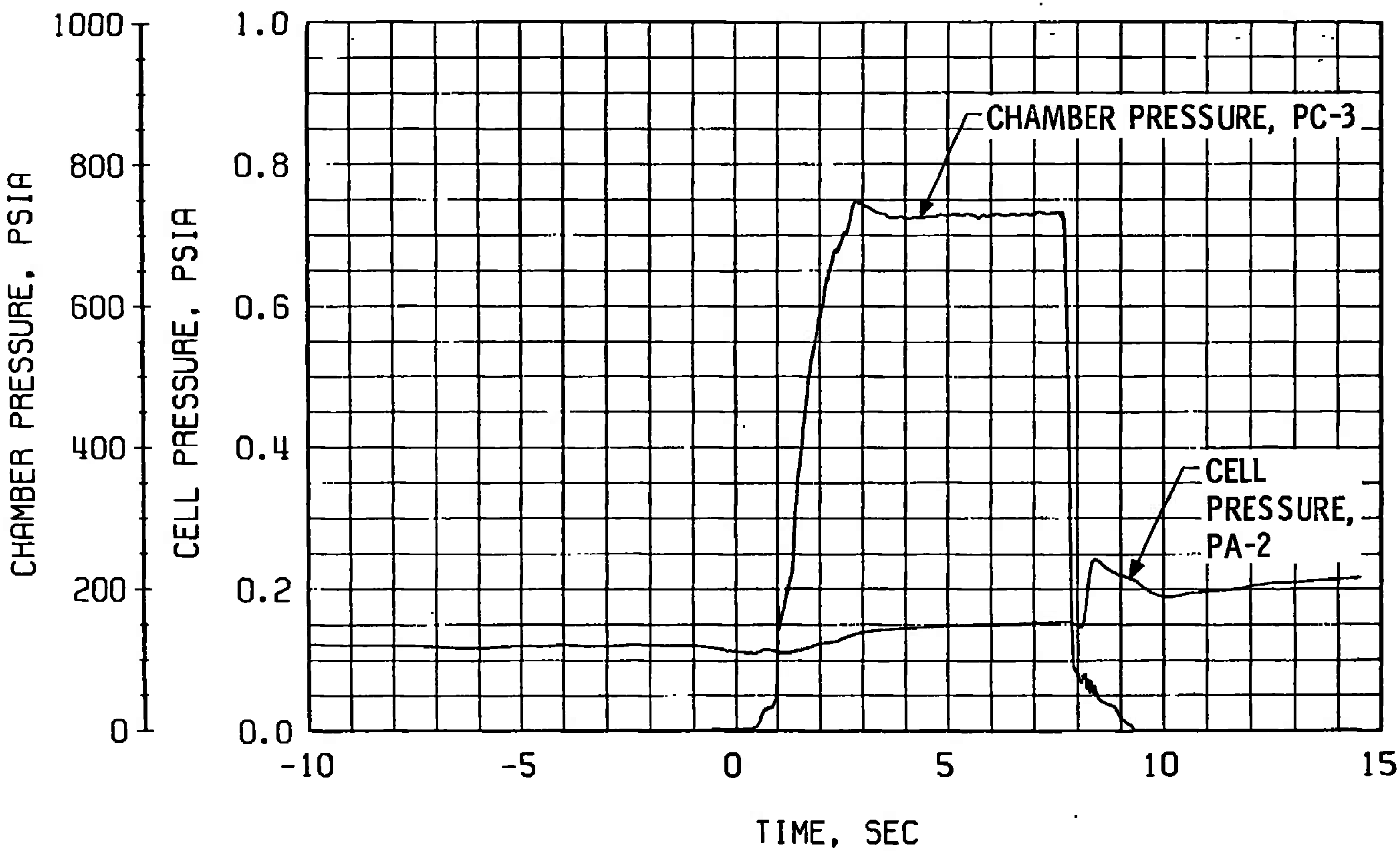
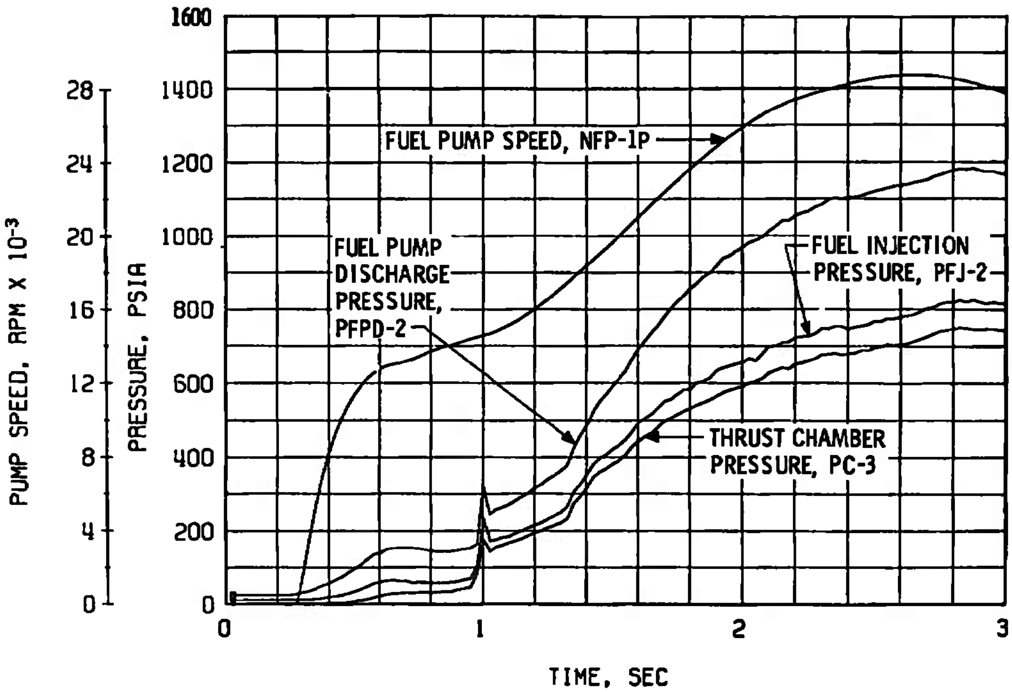
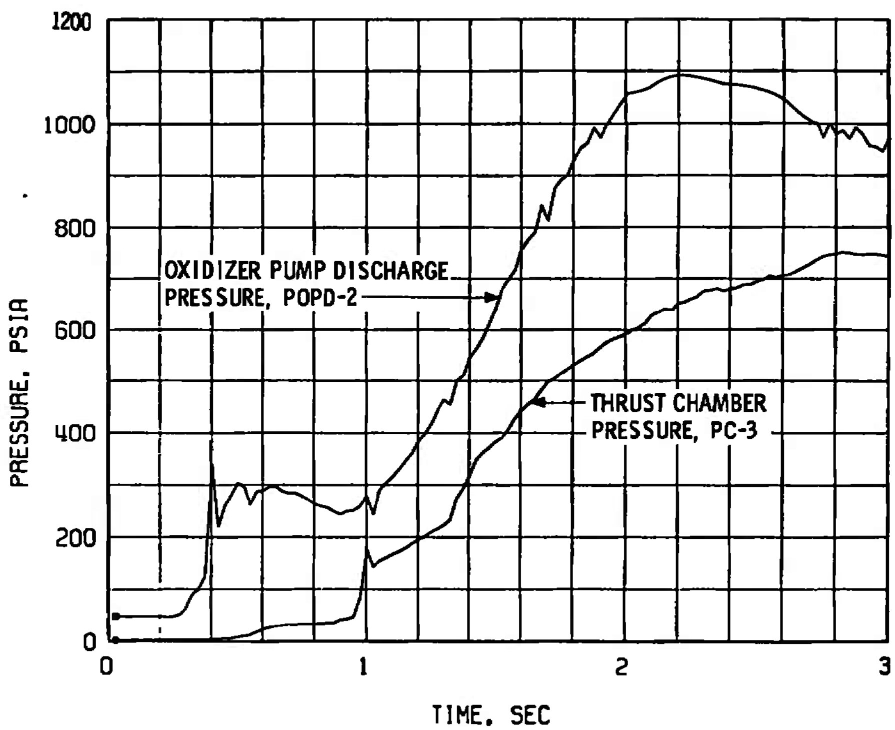


Fig. 18 Engine Chamber and Test Capsule Pressures, Firing 21C

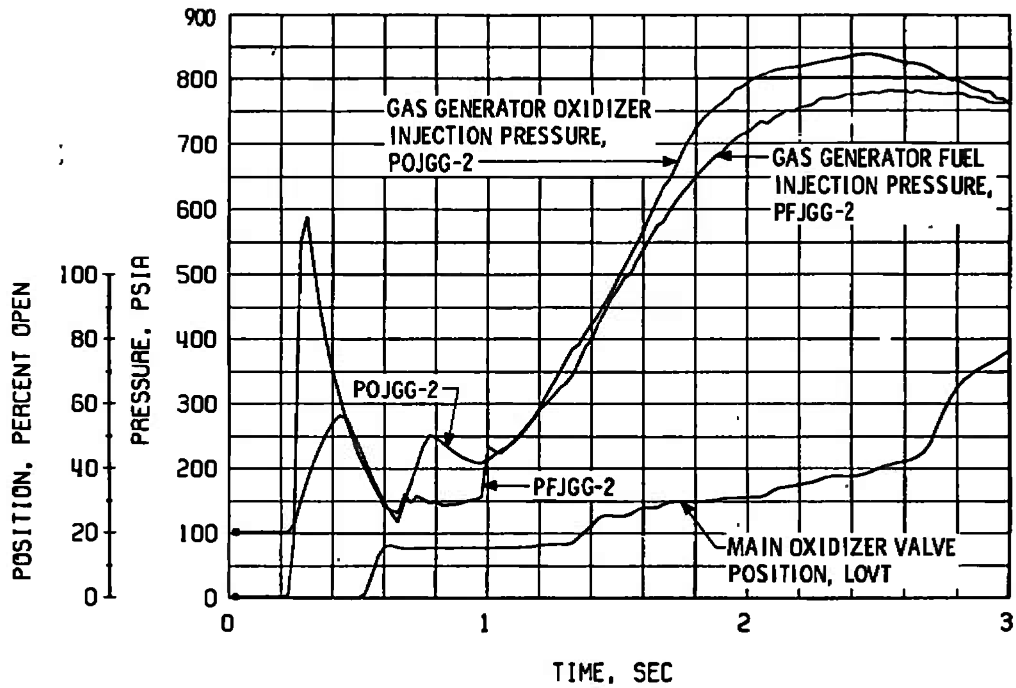


a. Start Transient, Thrust Chamber Fuel System

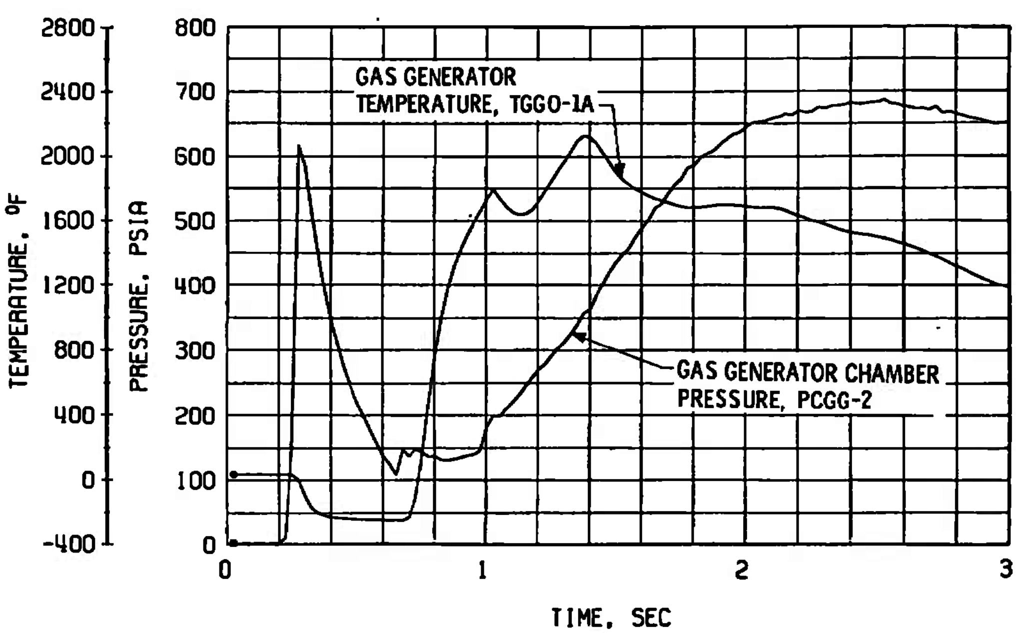


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 19 Engine Start and Shutdown Transients, Firing 21C

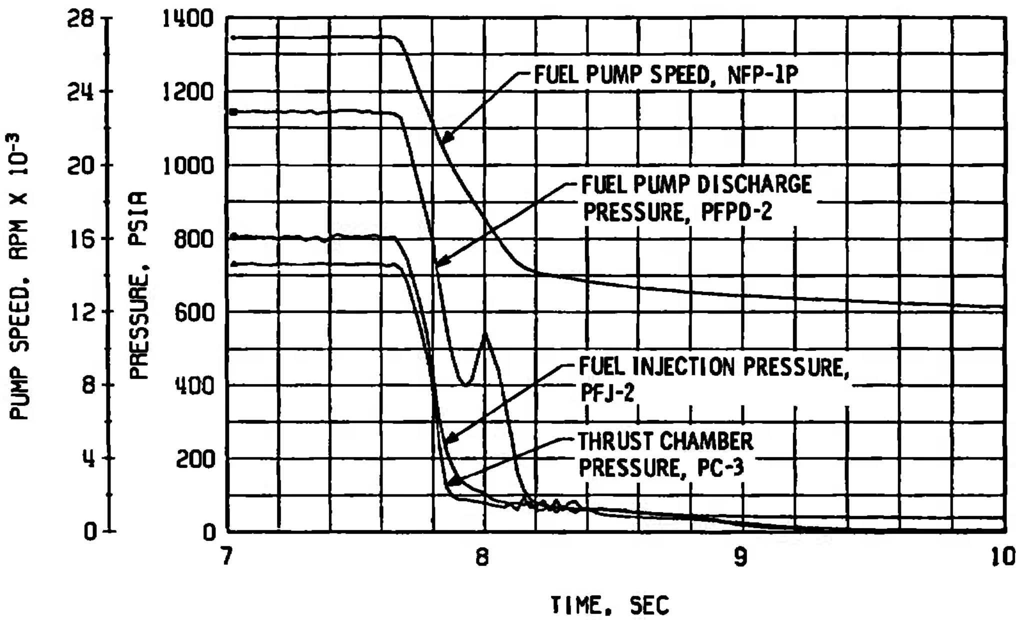


c. Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position

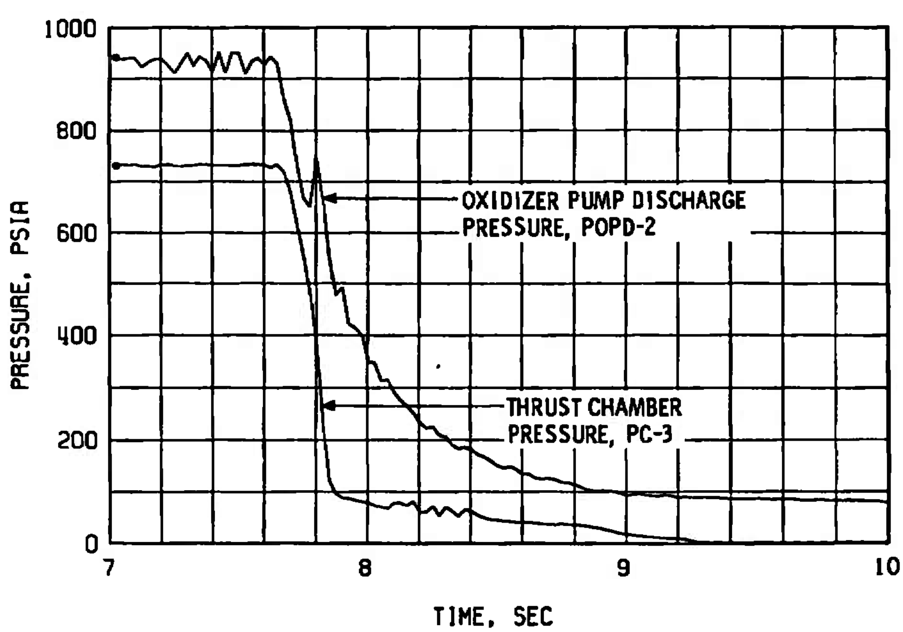


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 19 Continued

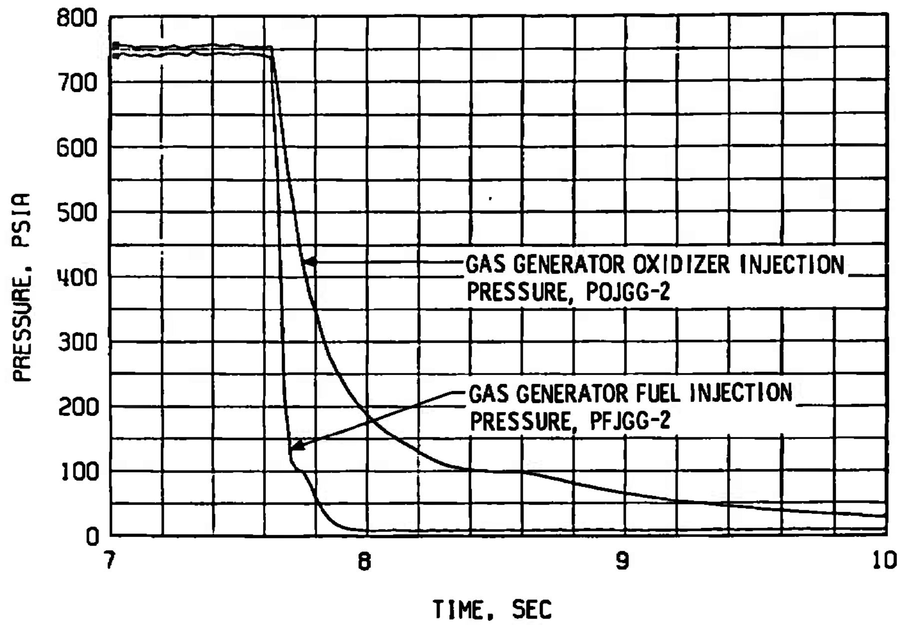


e. Shutdown Transient, Thrust Chamber Fuel System

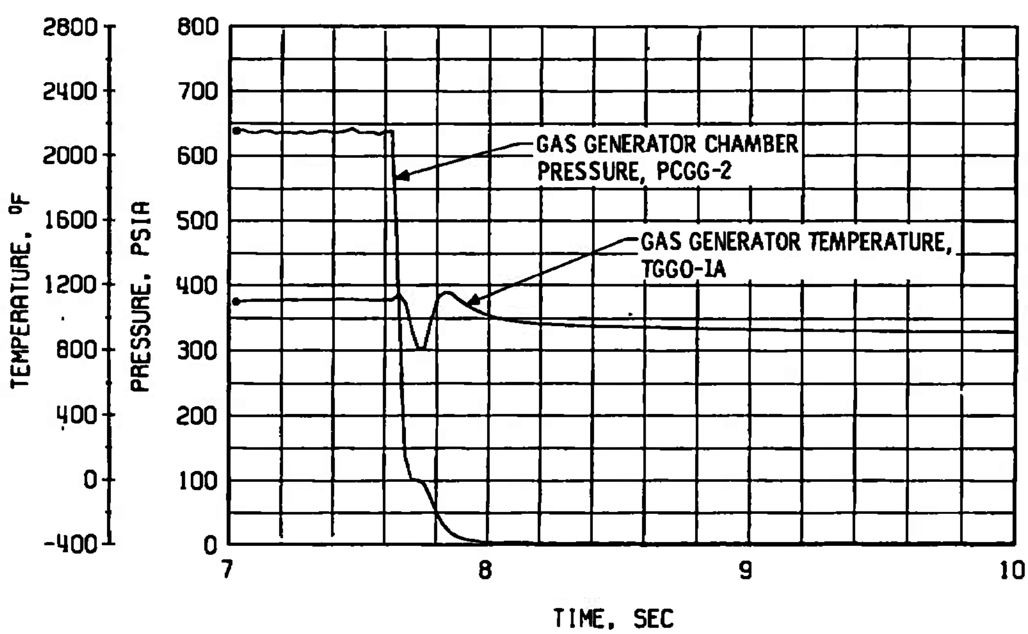


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 19 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 19 Concluded

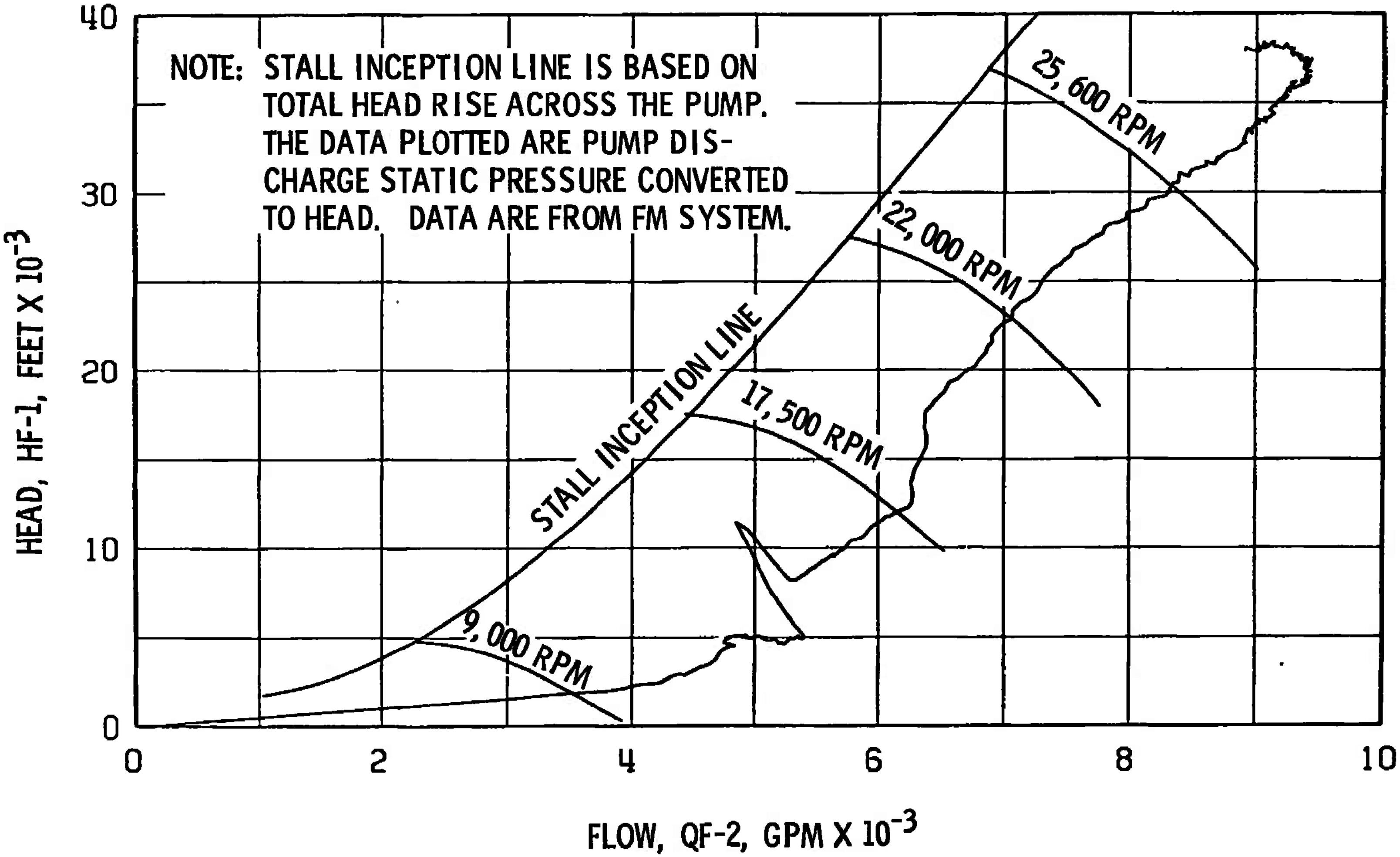
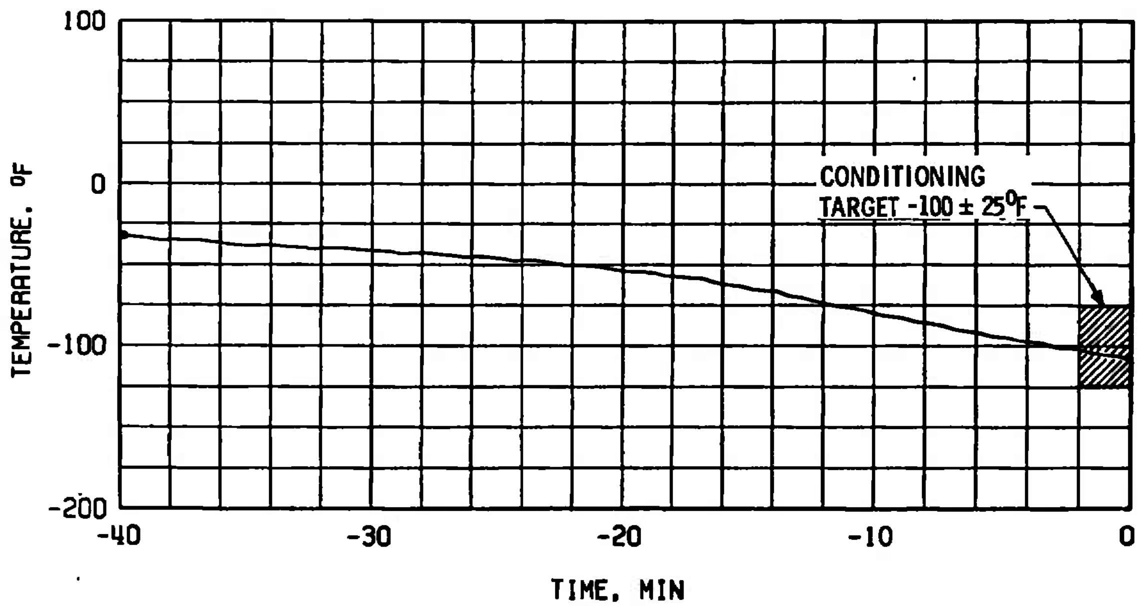
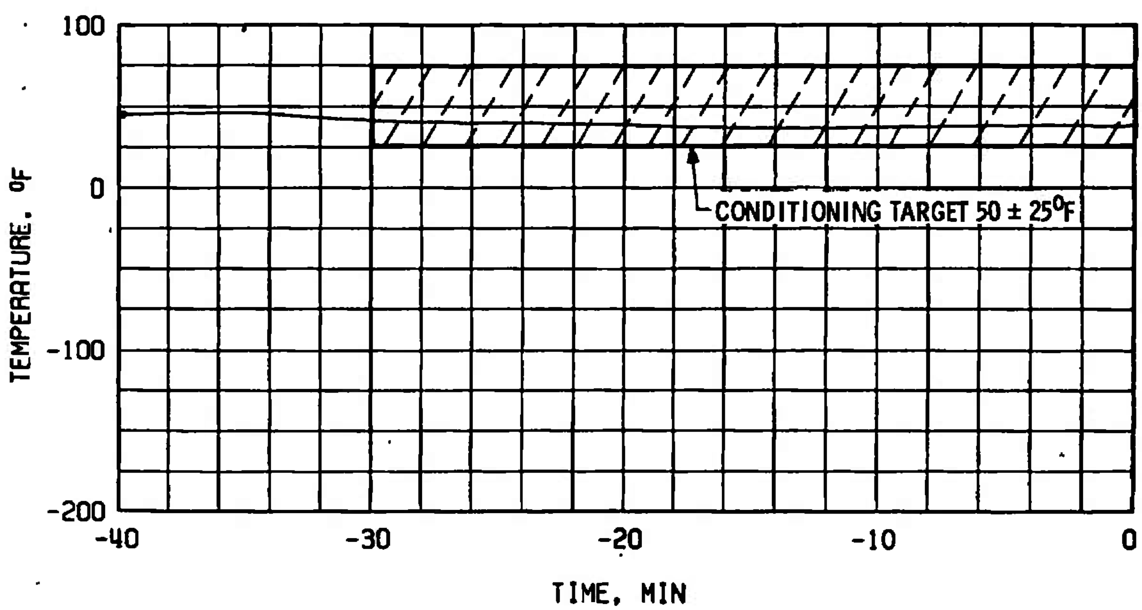


Fig. 20 Fuel Pump Transient Performance, Firing 21C

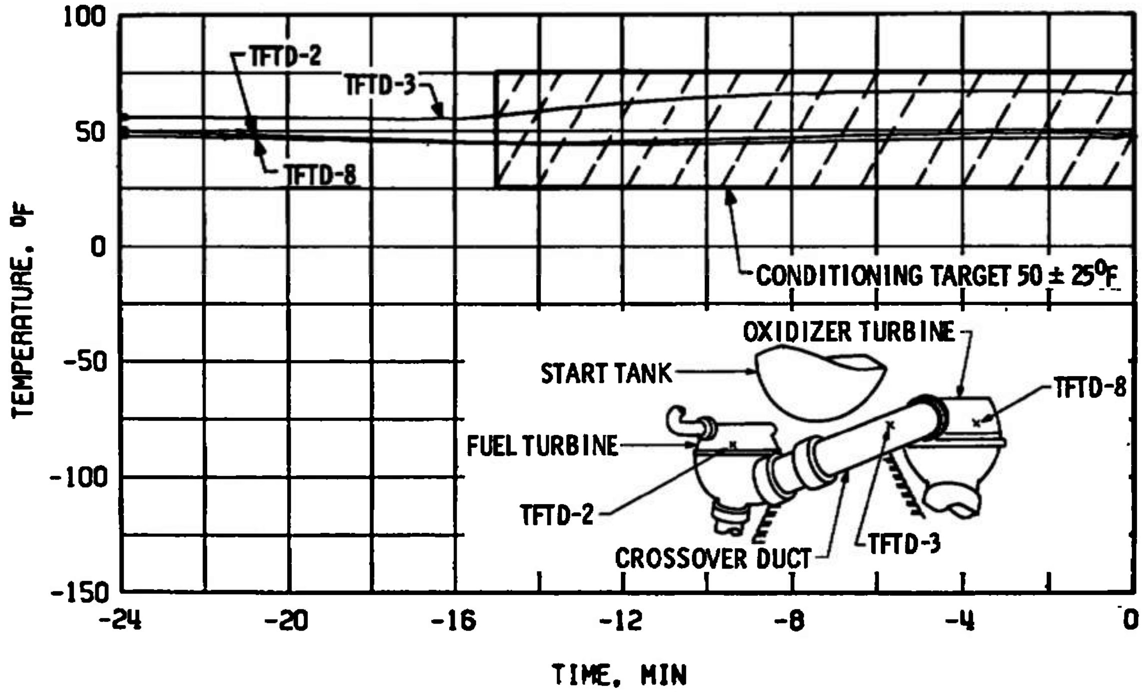


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

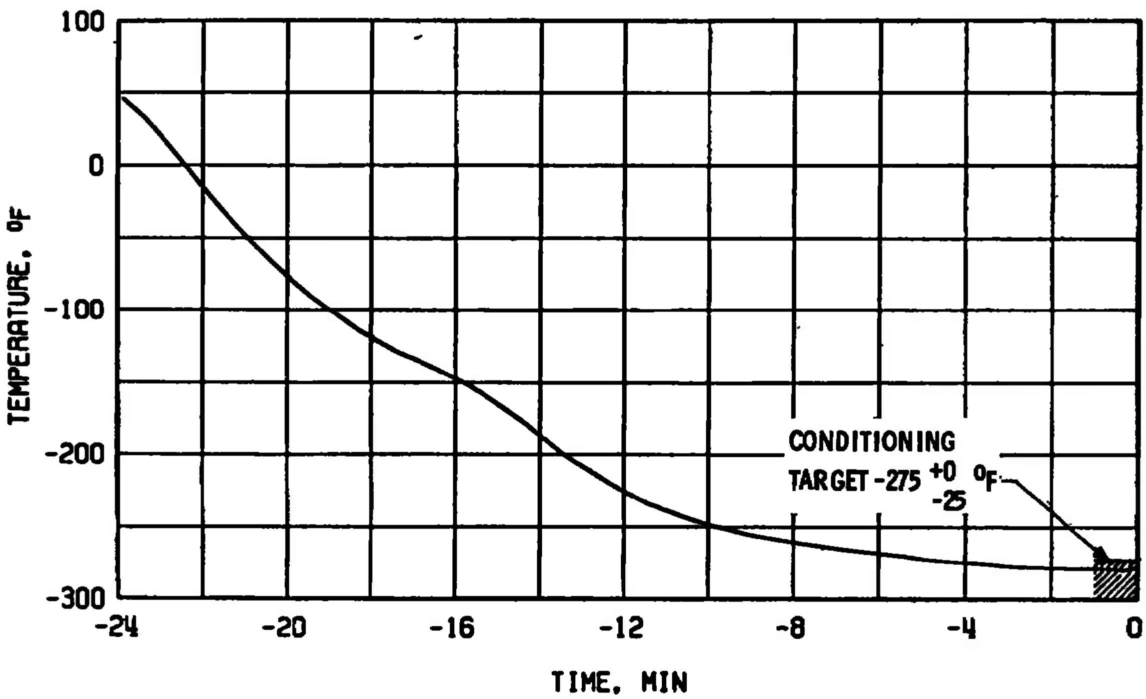


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 21 History of Firing 21D Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3 and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 21 Concluded

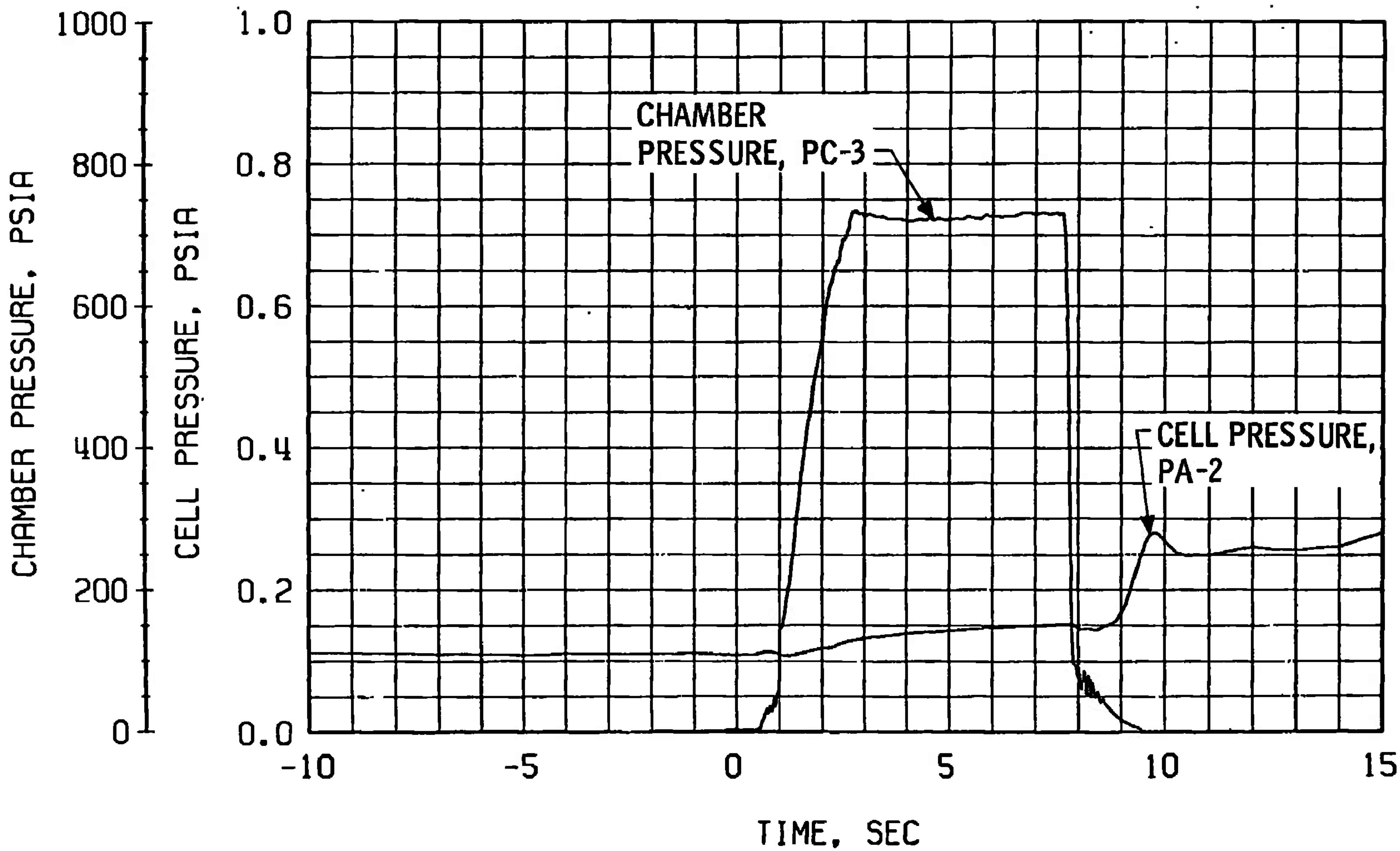
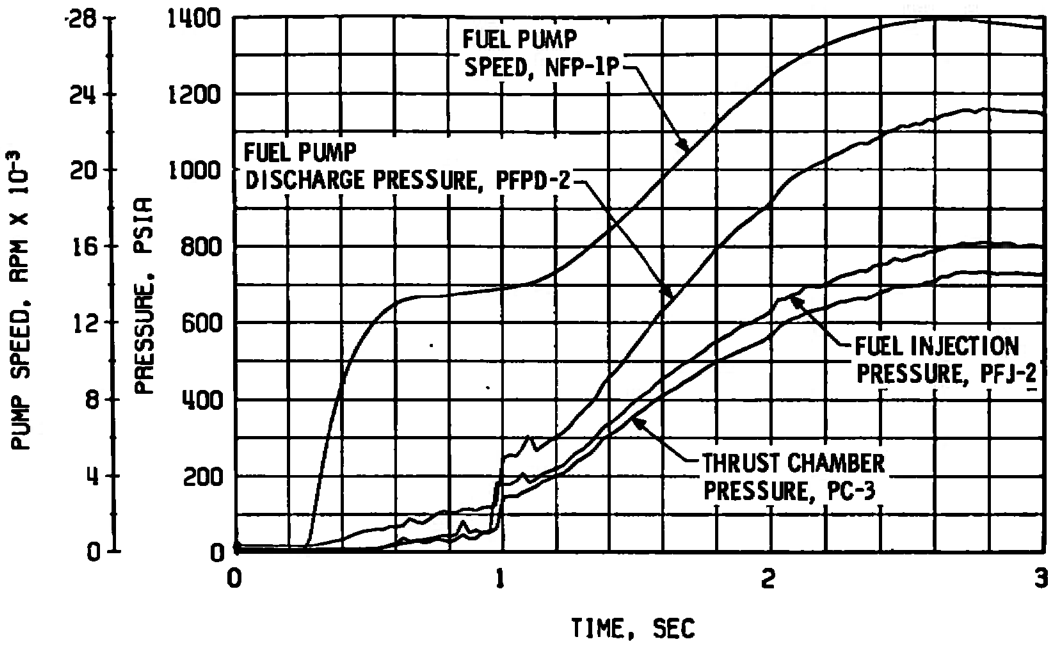
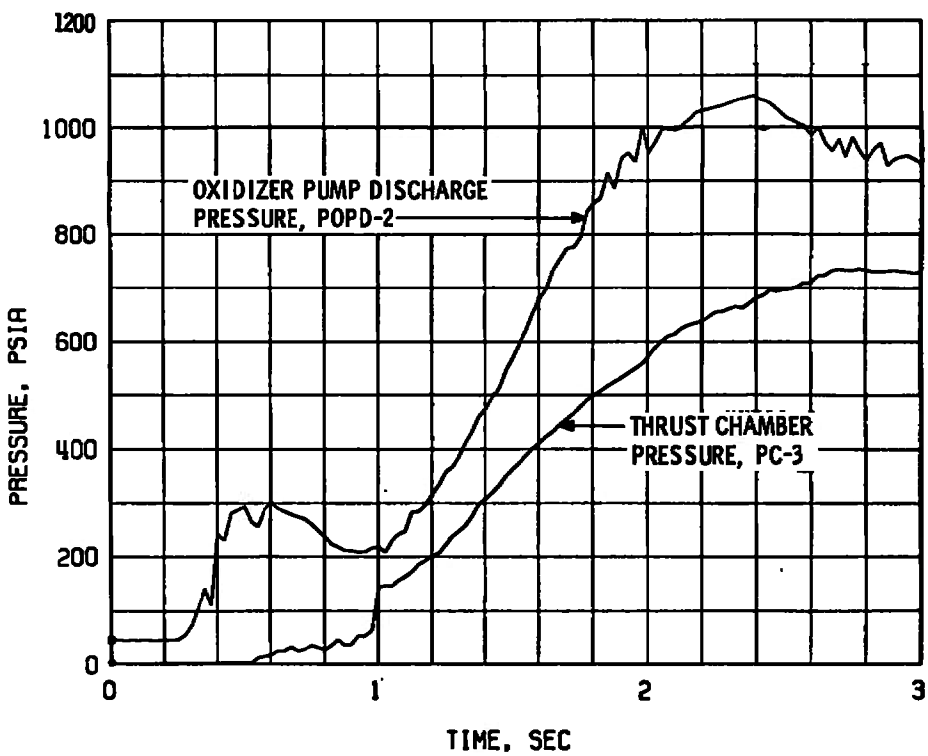


Fig. 22 Engine Chamber and Test Capsule Pressure, Firing 21D

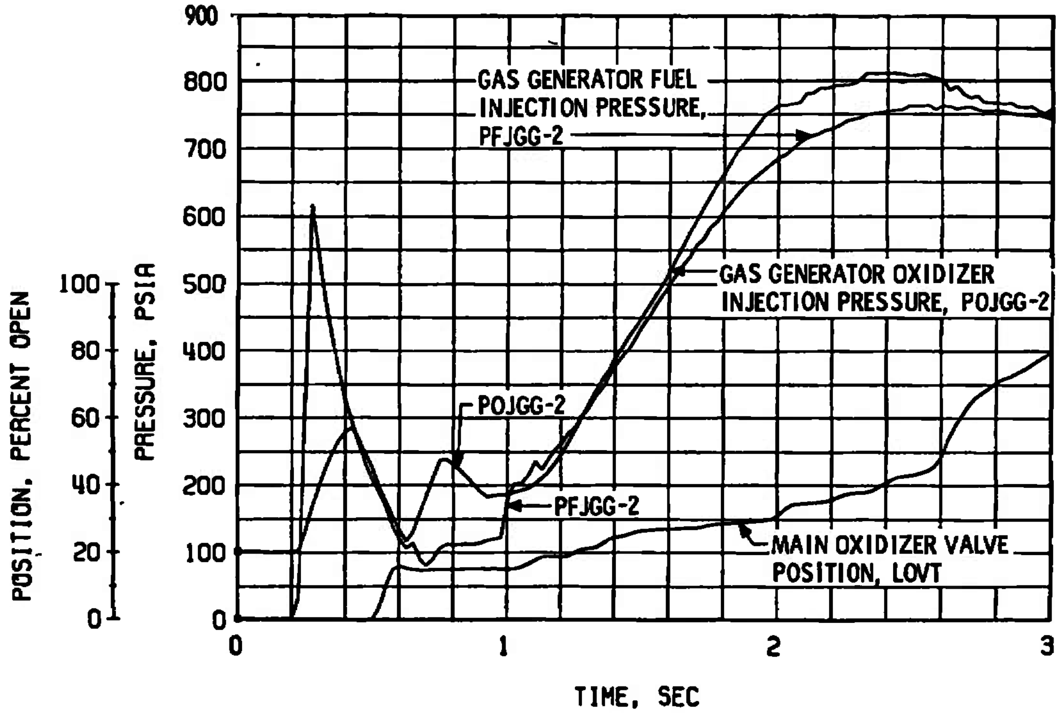


a. Start Transient, Thrust Chamber Fuel System

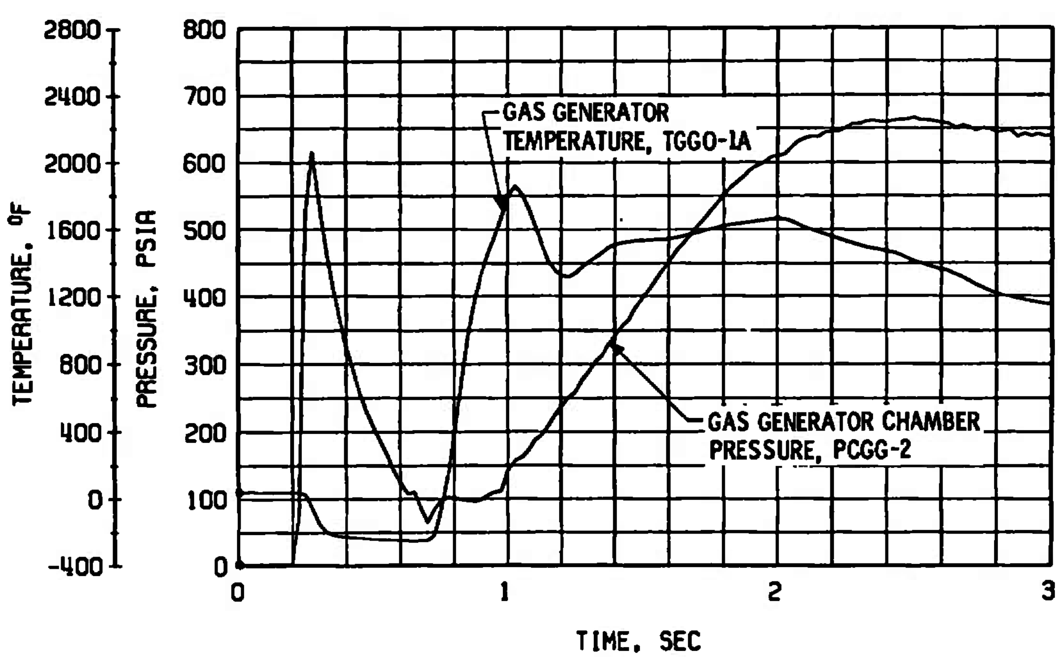


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 23 Engine Start and Shutdown Transients, Firing 21D

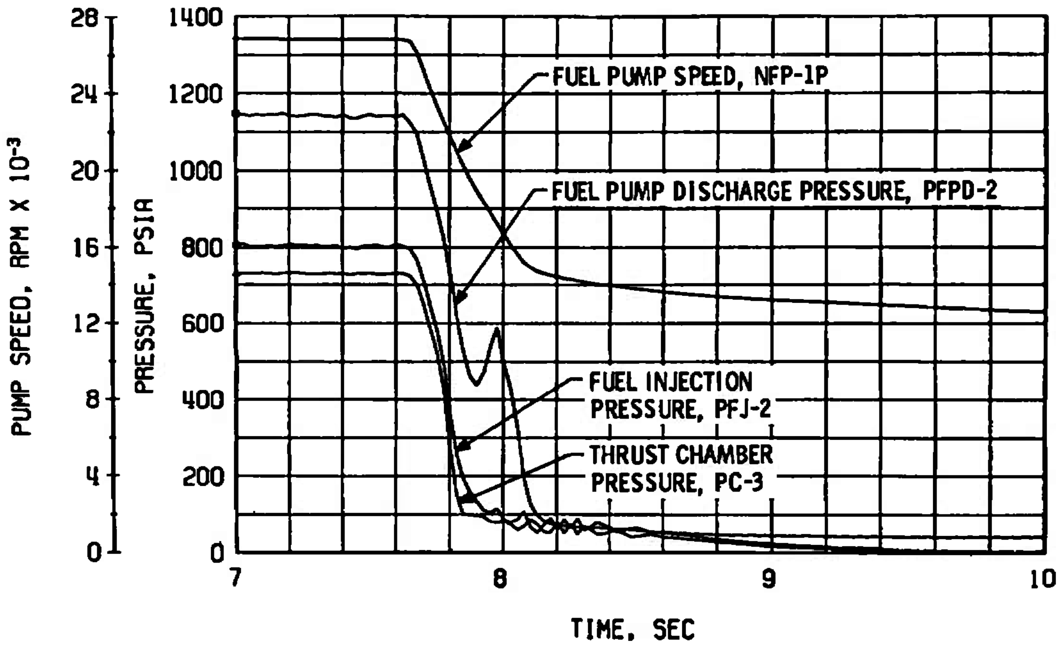


c. Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position

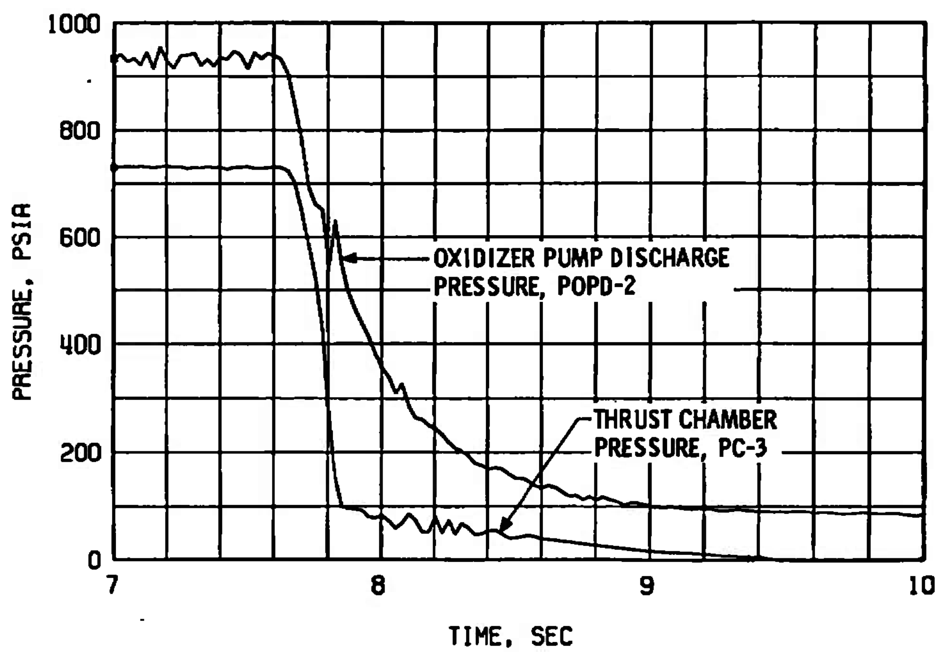


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 23 Continued

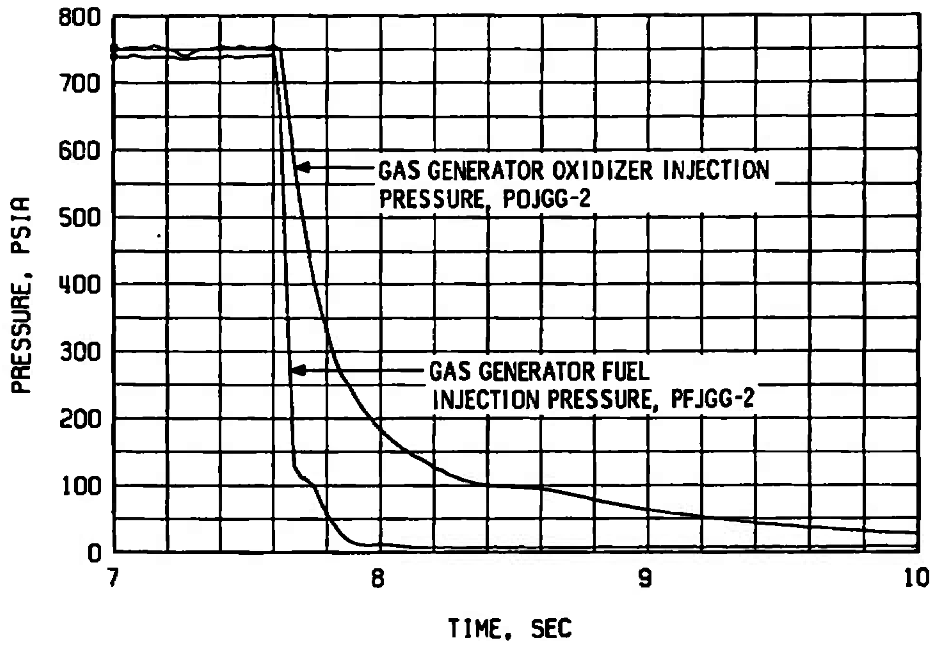


e. Shutdown Transient, Thrust Chamber Fuel System

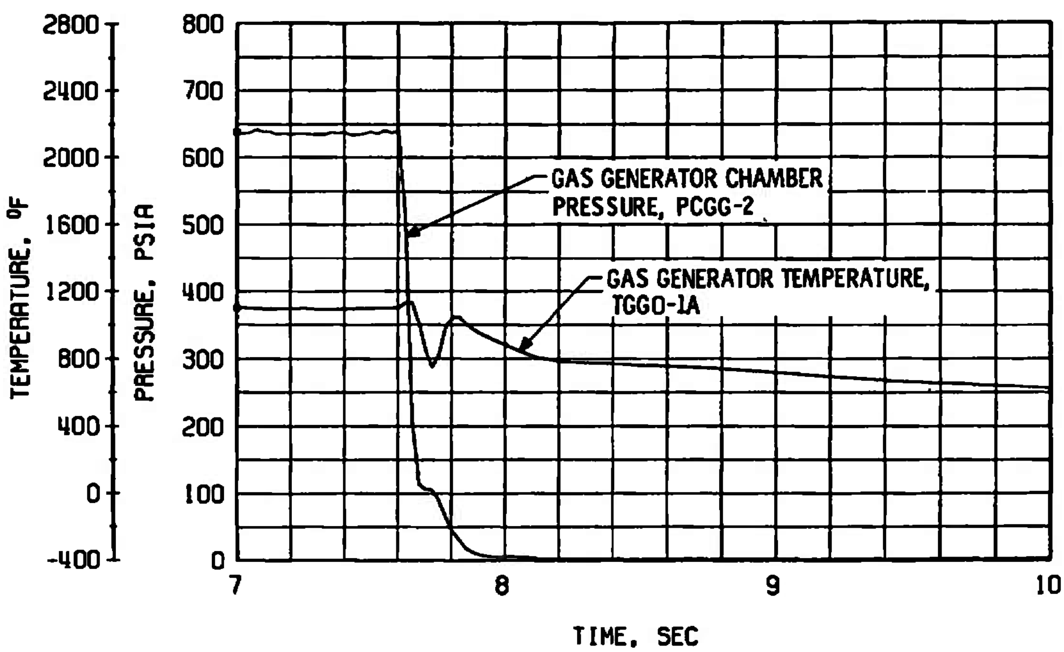


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 23 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 23 Concluded

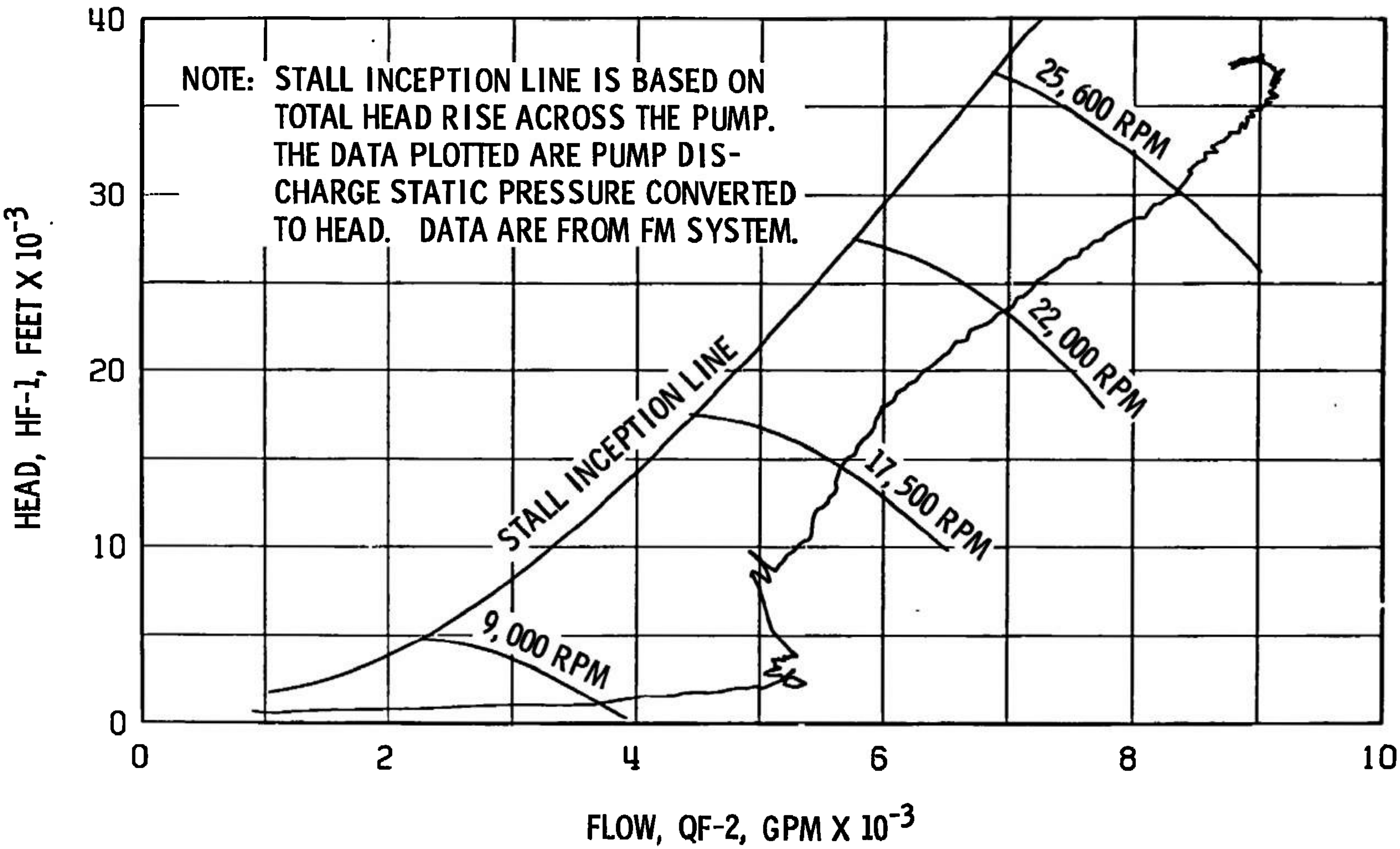
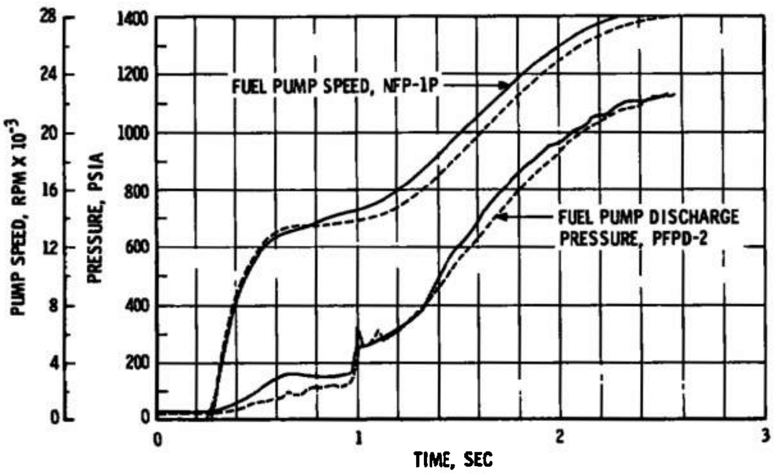
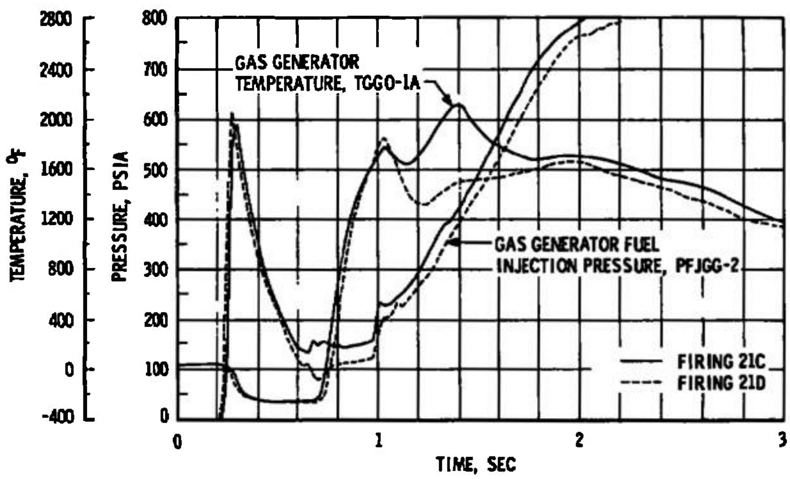


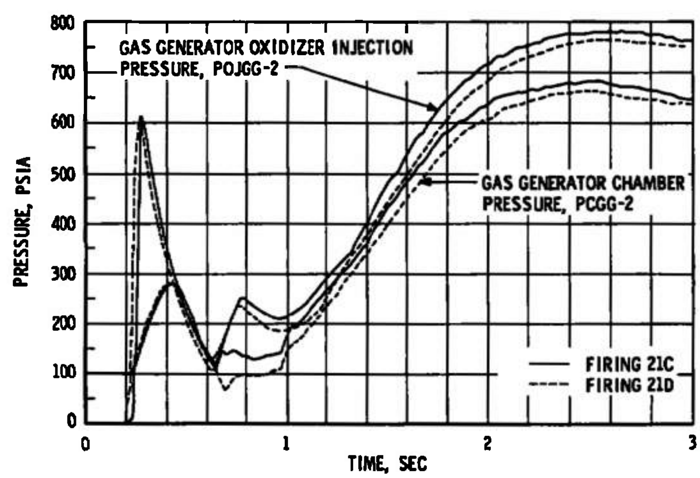
Fig. 24 Fuel Pump Transient Performance, Firing 21D



a. Fuel Pump Speed and Discharge Pressure

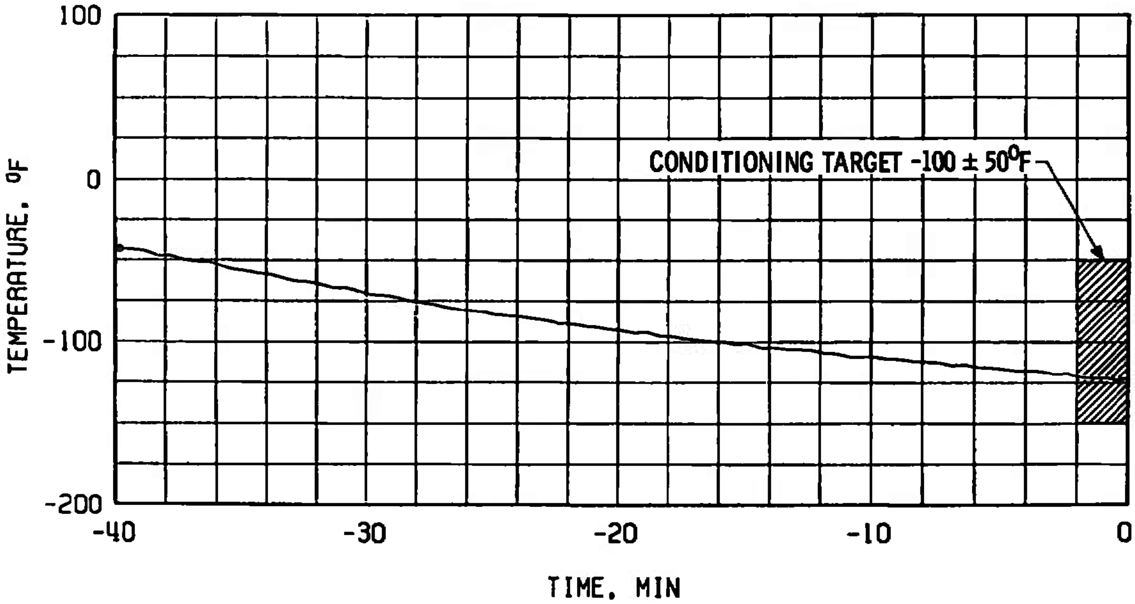


b. Gas Generator Fuel Injection Pressure and Gas Generator Temperature

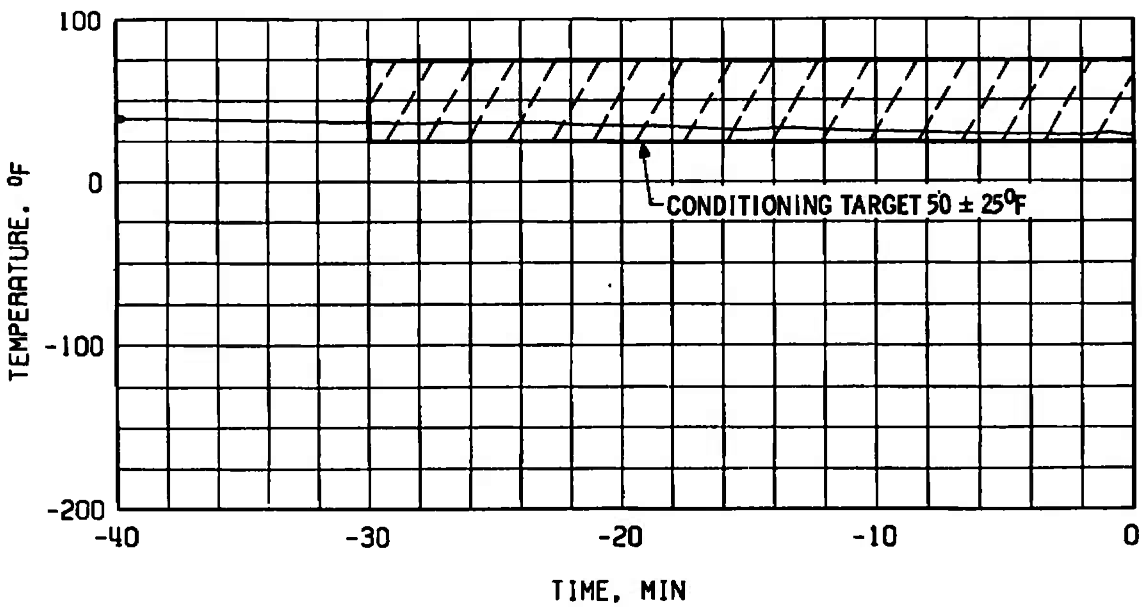


c. Gas Generator Oxidizer Injection and Chamber Pressure

Fig. 25 Comparison of Firing 21C and 21D Start Transient Parameters

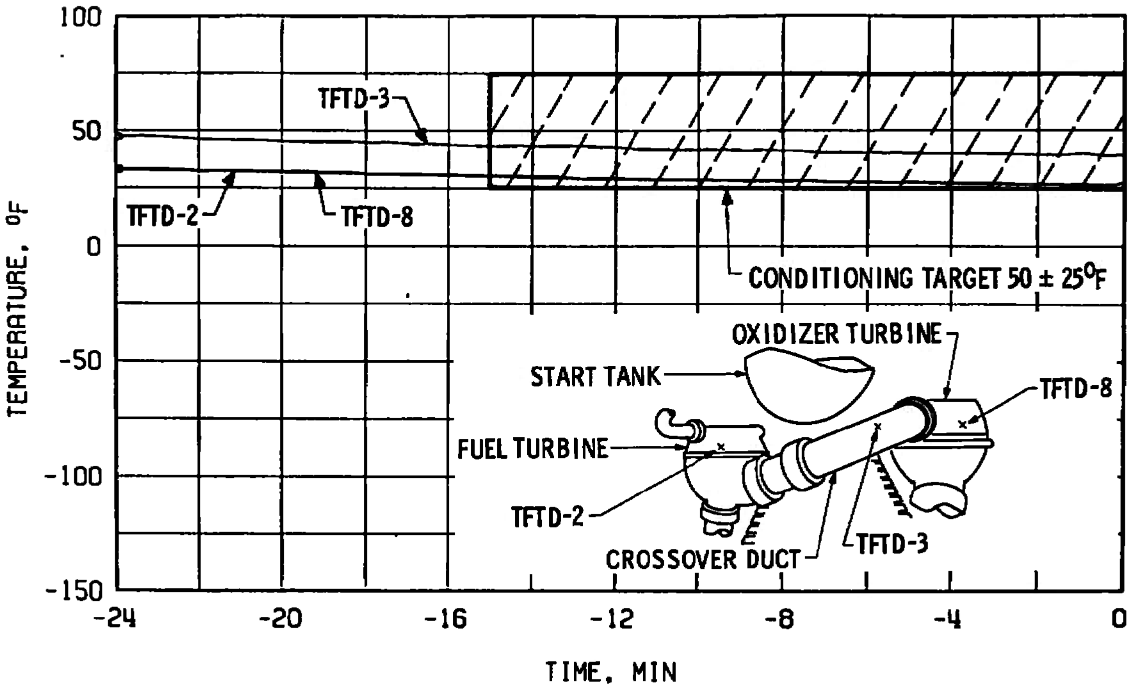


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

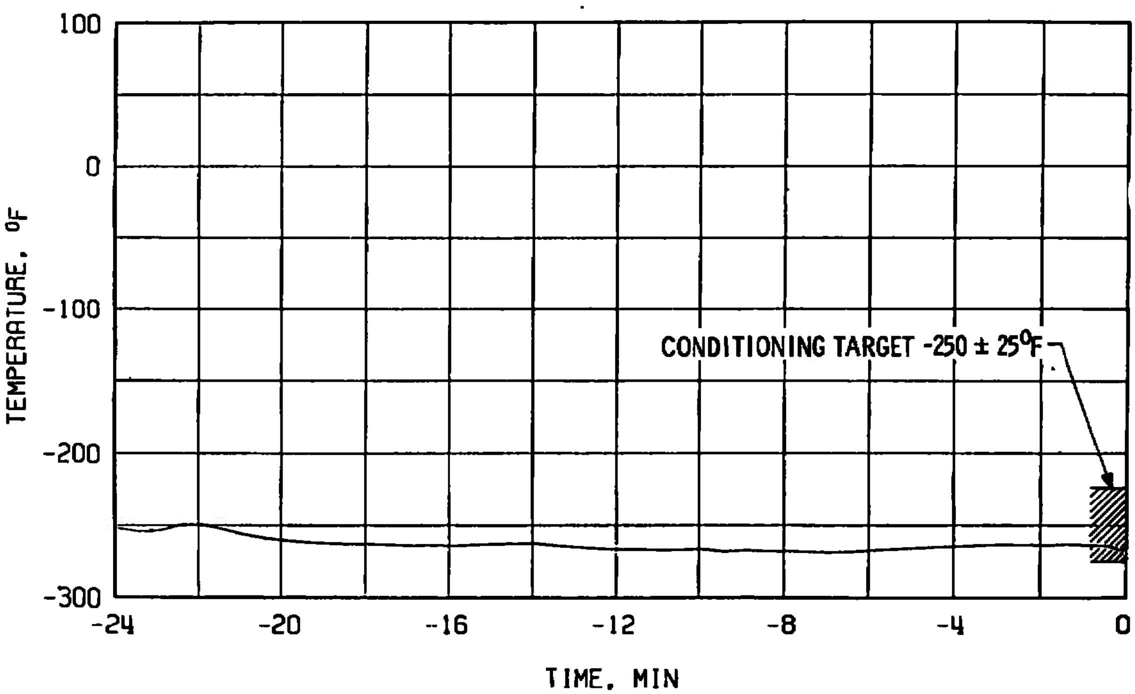


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 26 History of Firing 22A Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3, and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 26 Concluded

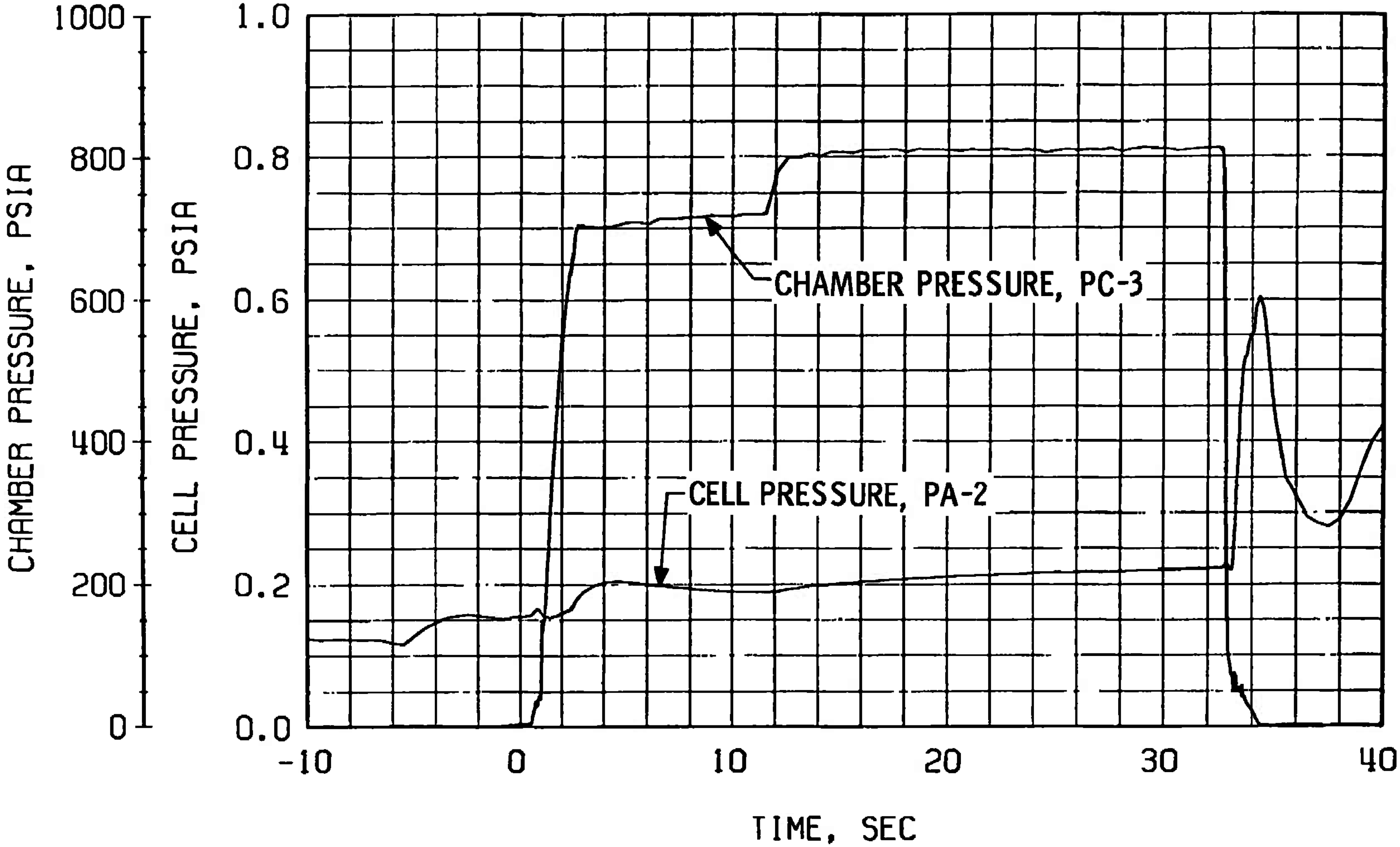
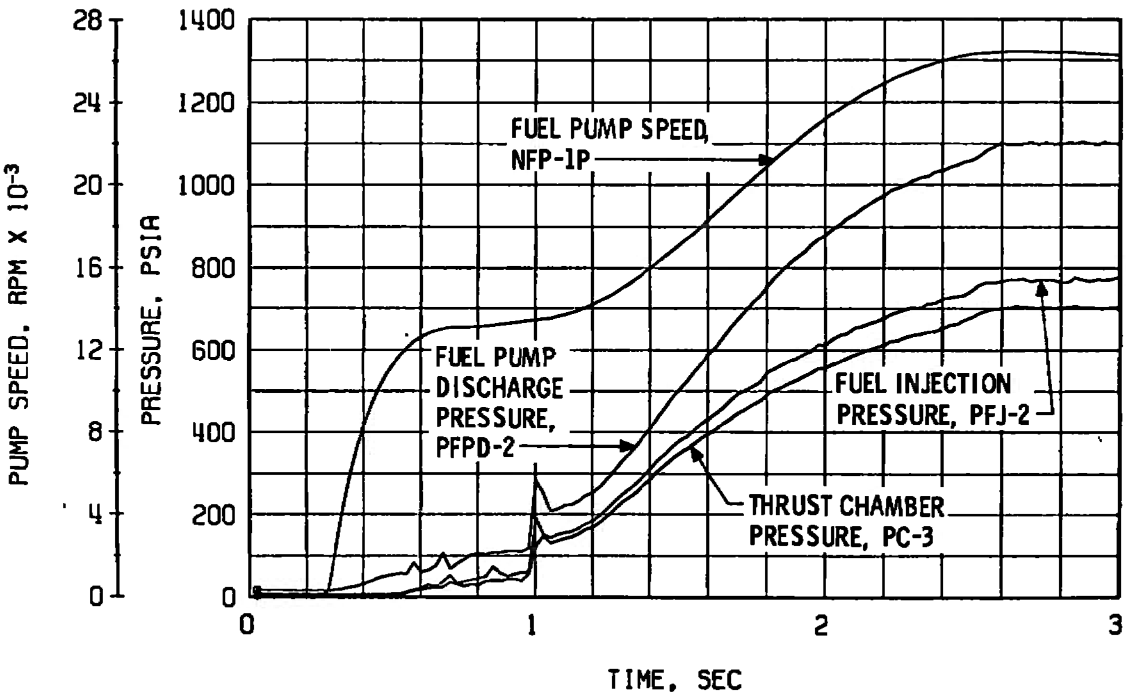
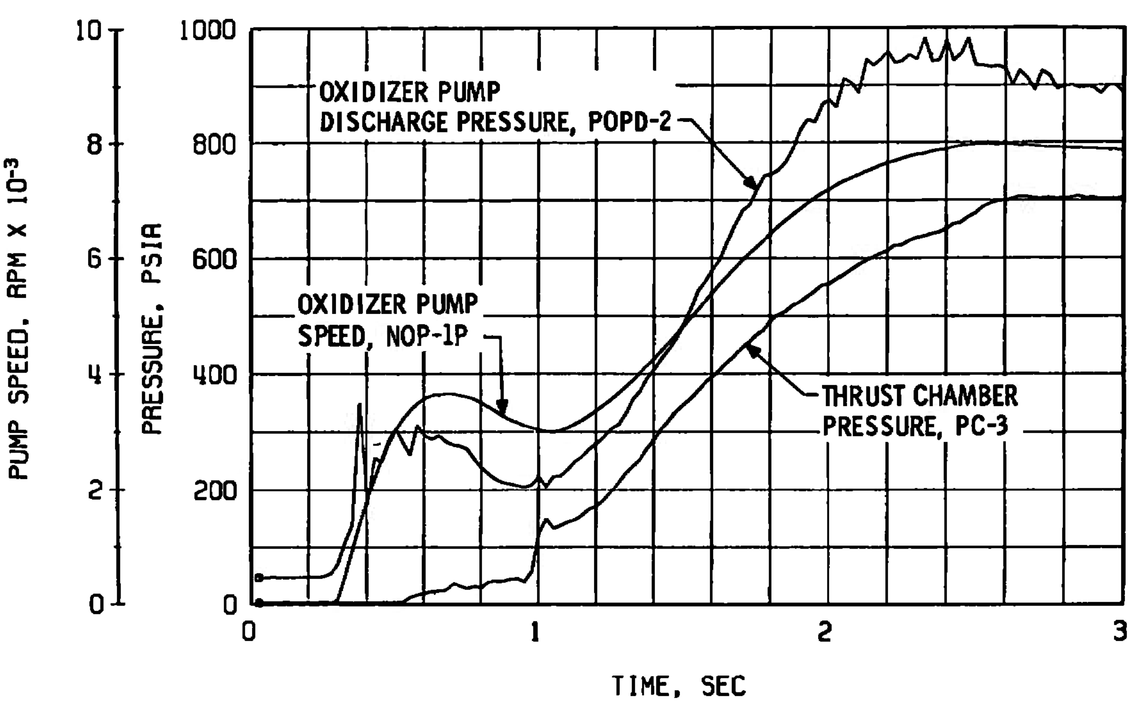


Fig. 27 Engine Chamber and Test Cell Pressure, Firing 22A

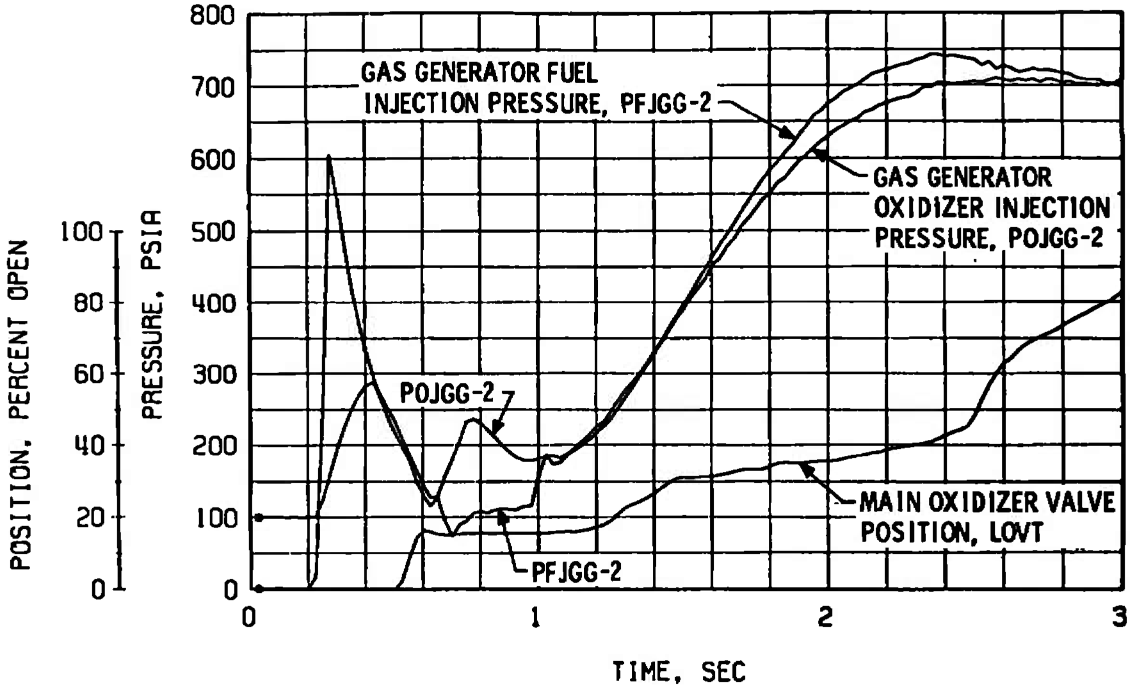


a. Start Transient, Thrust Chamber Fuel System

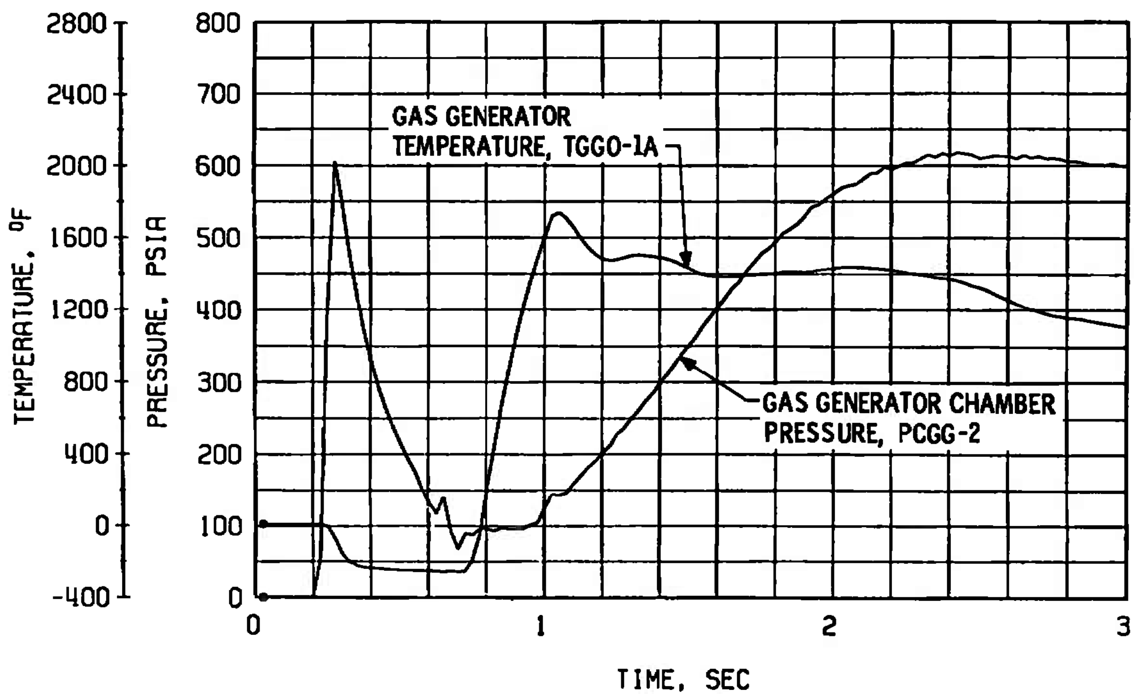


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 28 Engine Start and Shutdown Transients, Firing 22A

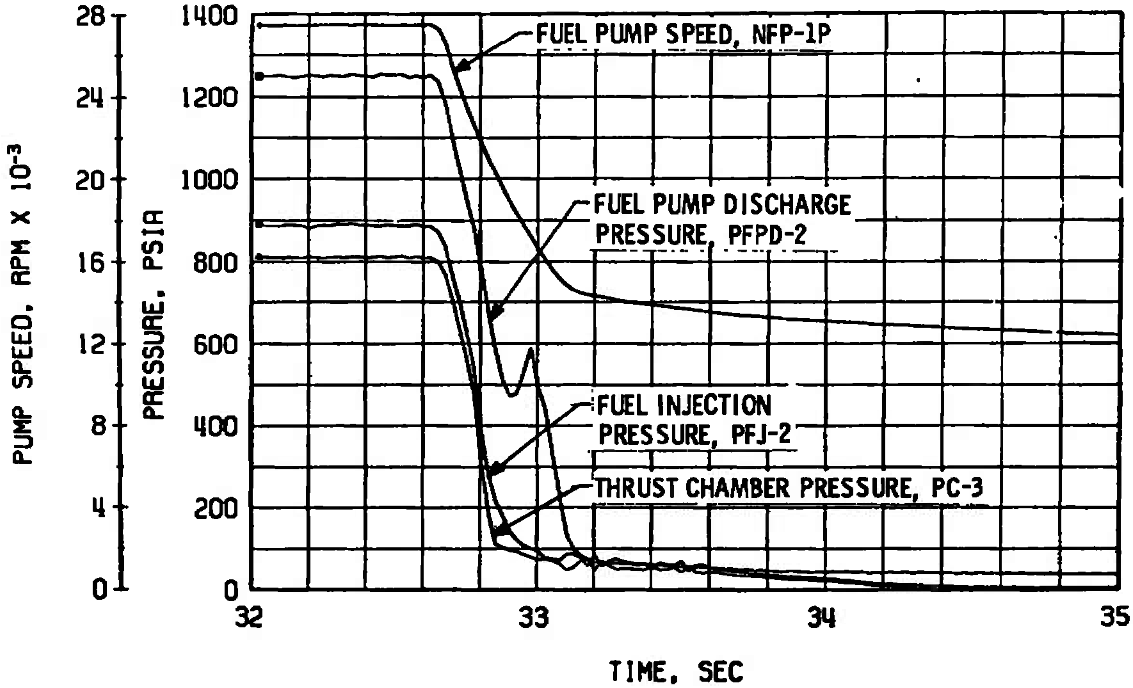


c. Start Transient, Generator Injection Pressures and Main Oxidizer Valve Position

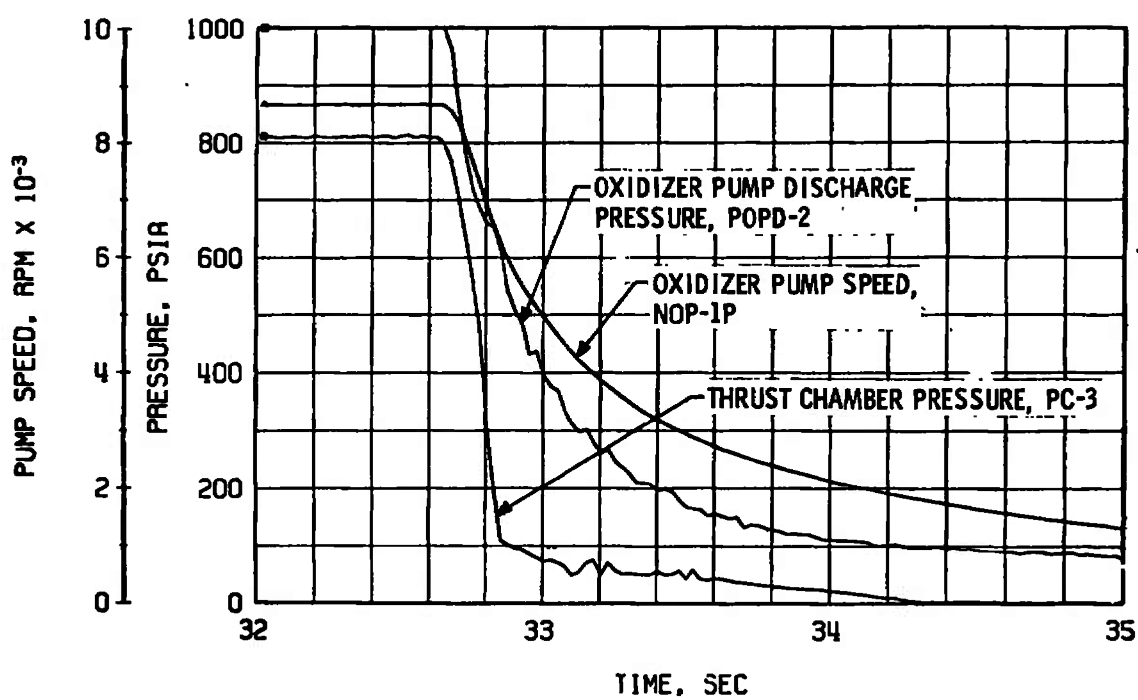


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 28 Continued

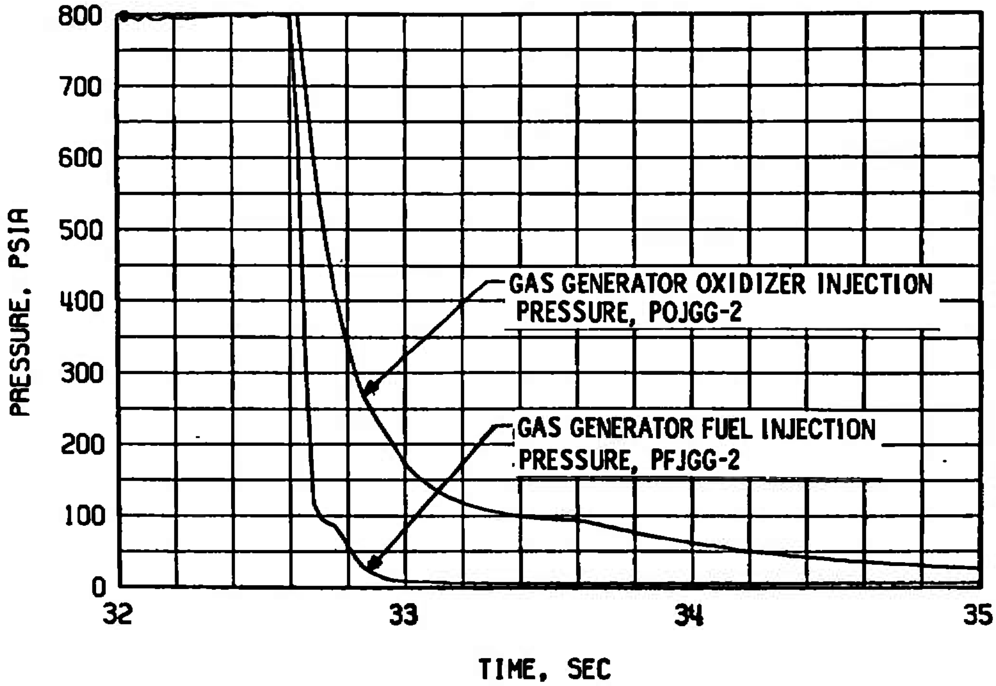


e. Shutdown Transient, Thrust Chamber Fuel System

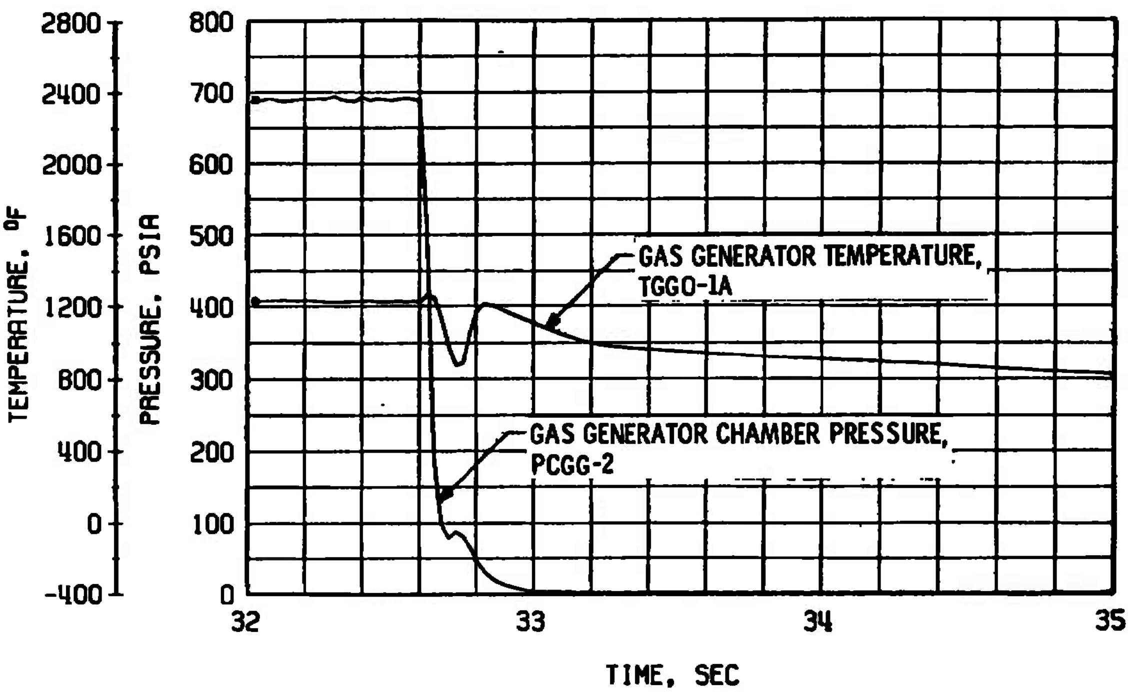


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 28 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 28 Concluded

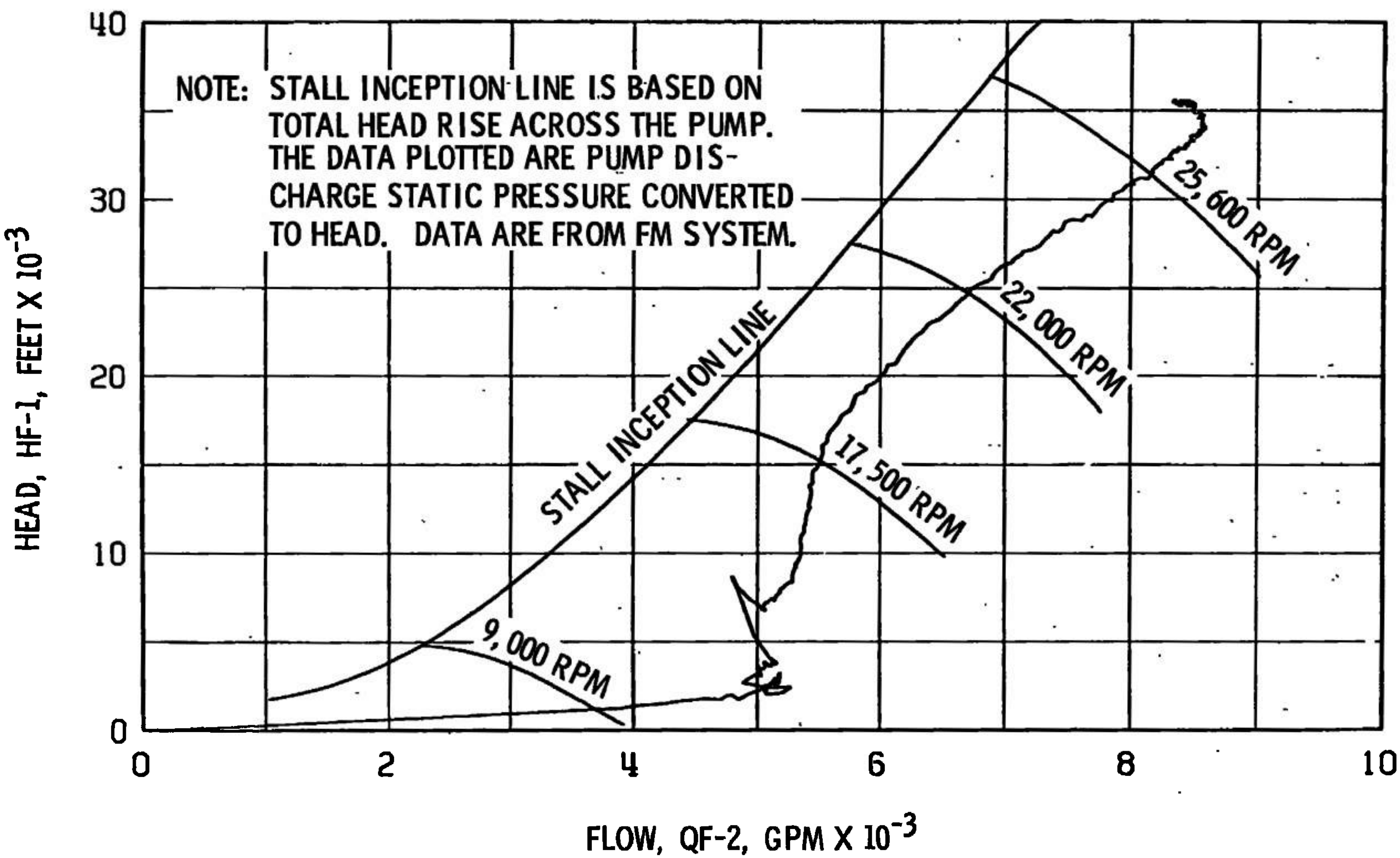
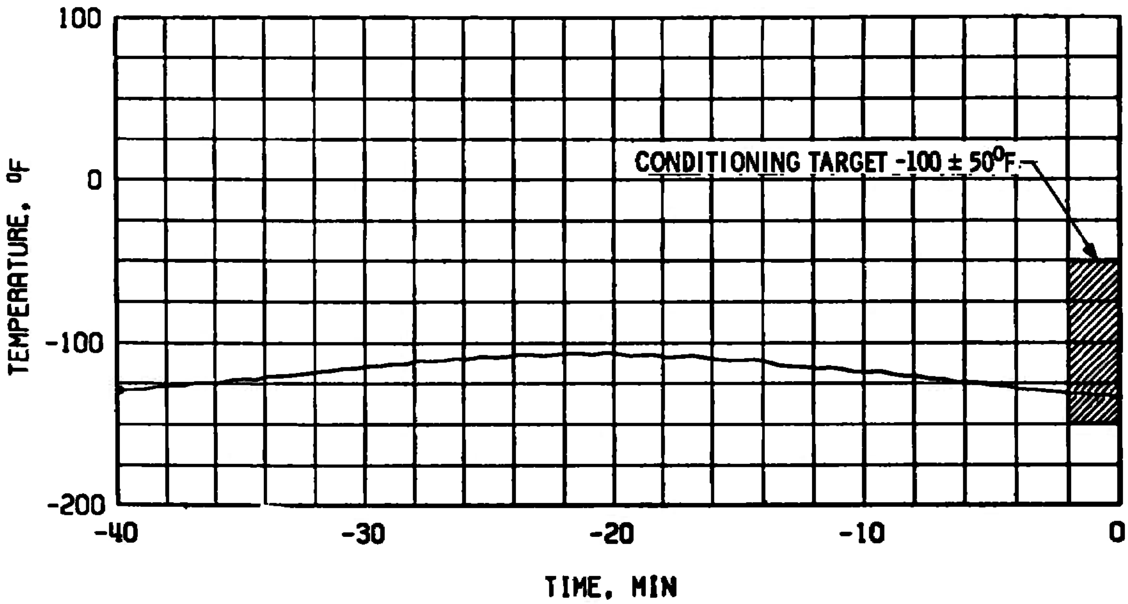
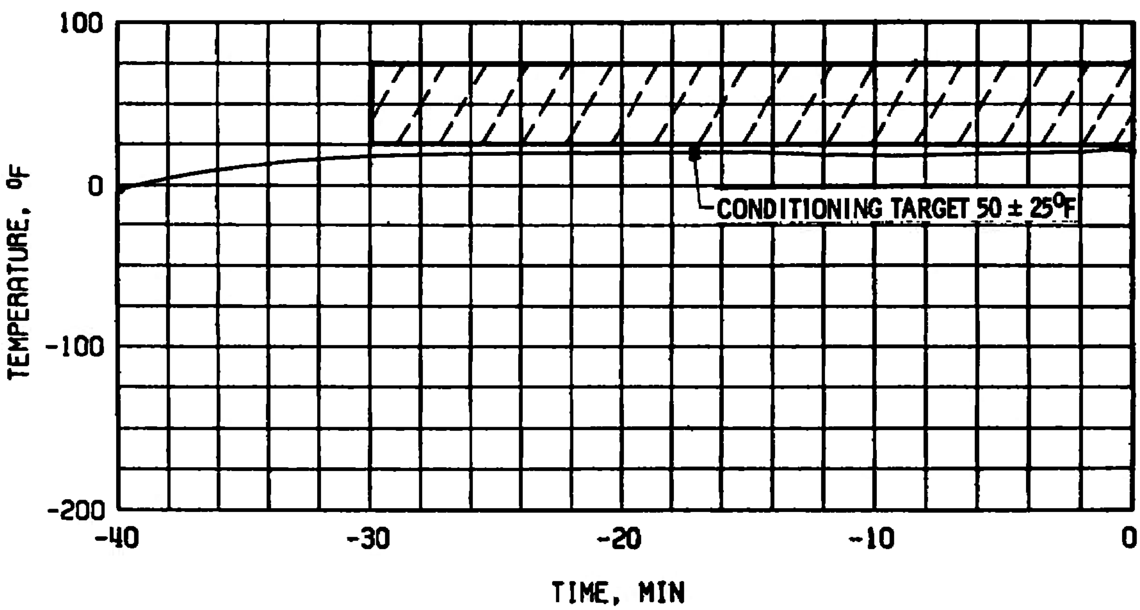


Fig. 29 Fuel Pump Transient Performance, Firing 22A

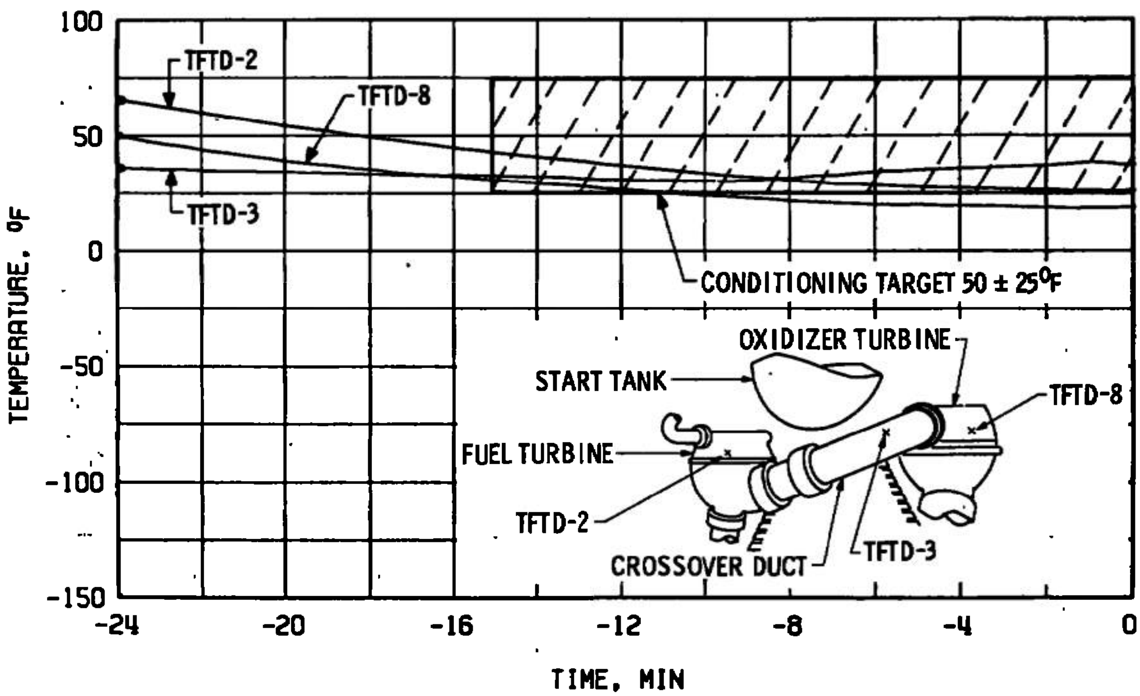


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

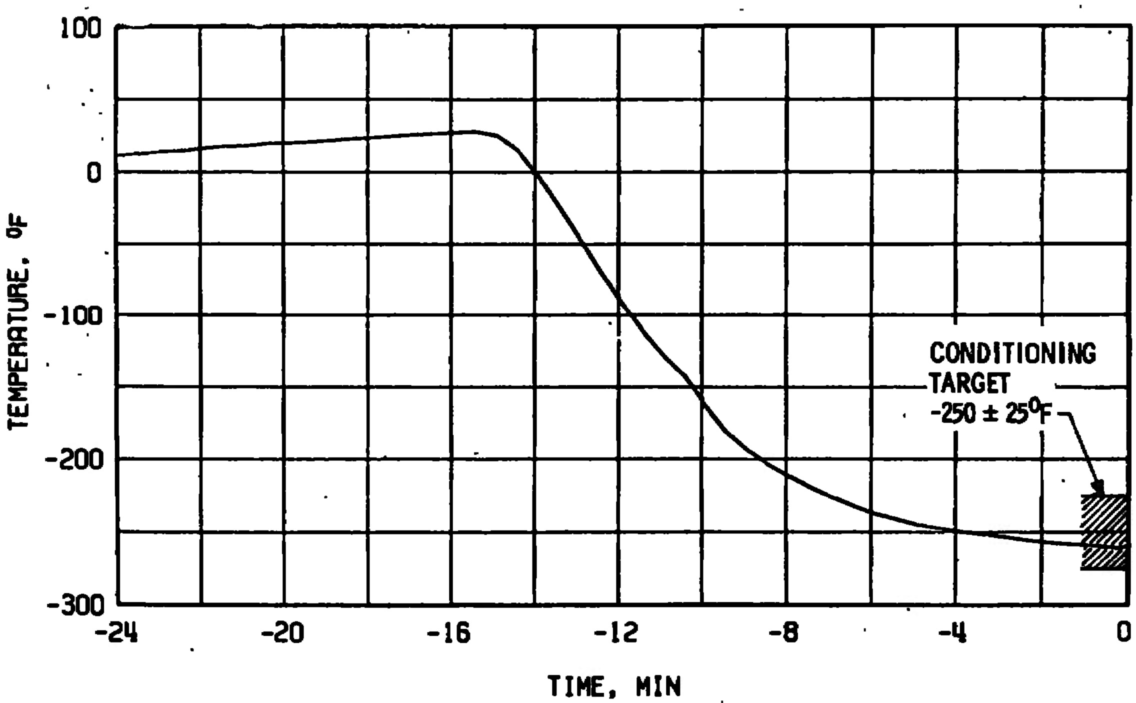


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 30 History of Firing 22B Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3 and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 30 Concluded

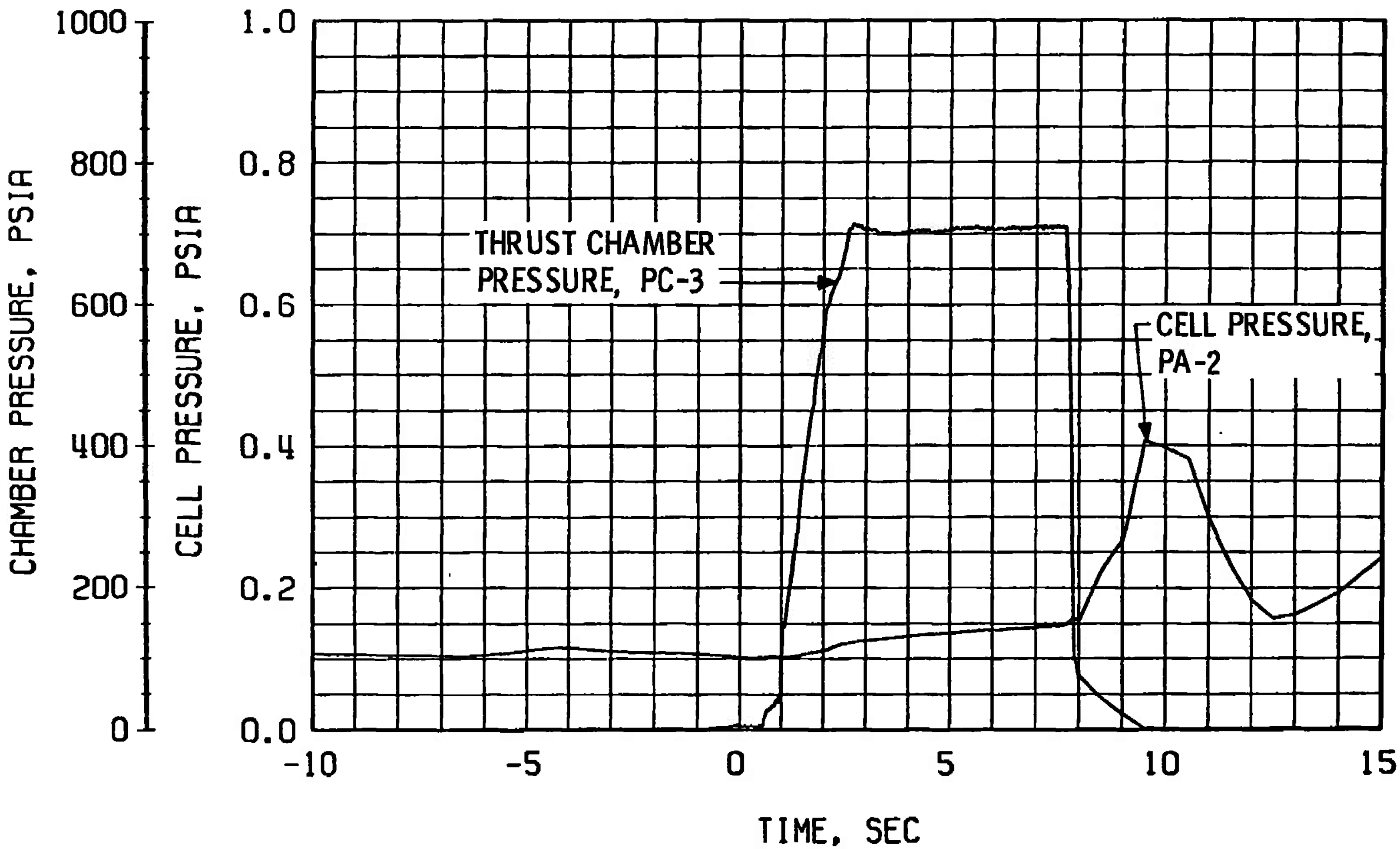
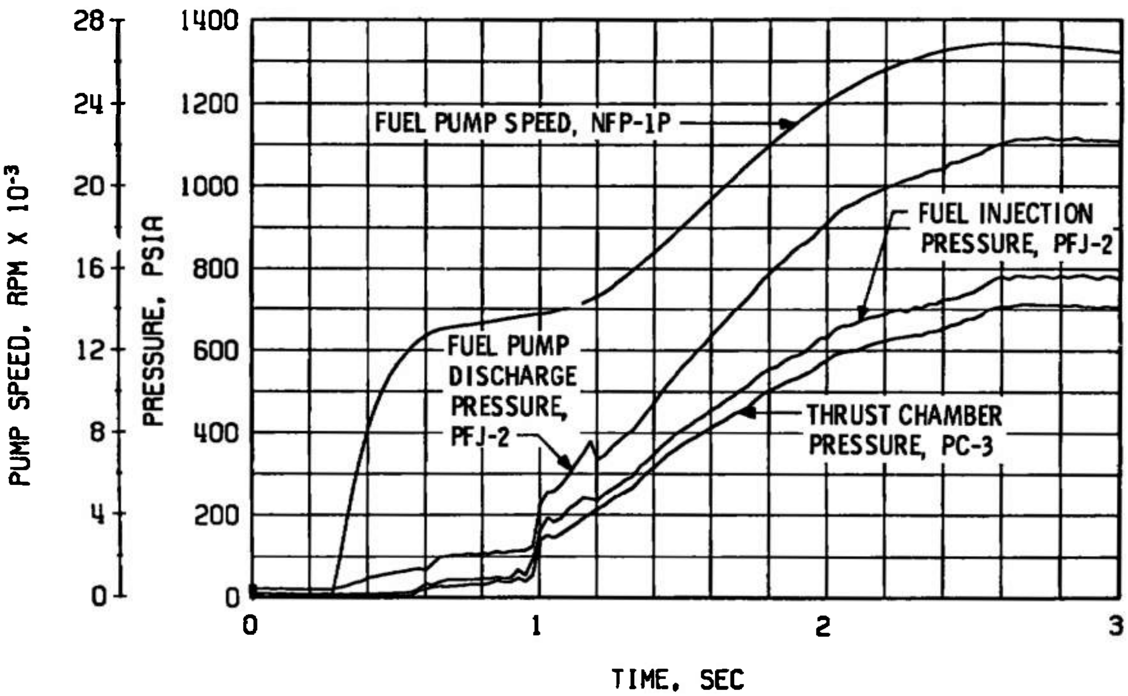
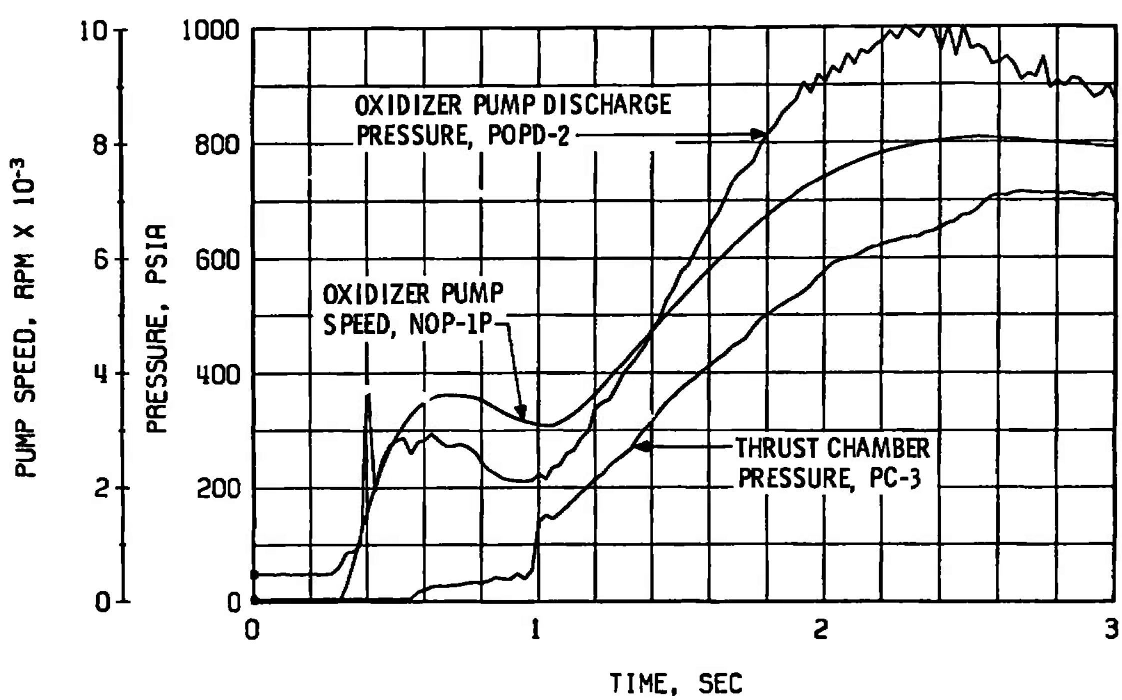


Fig. 31 Engine Chamber and Test Cell Pressure, Firing 22B

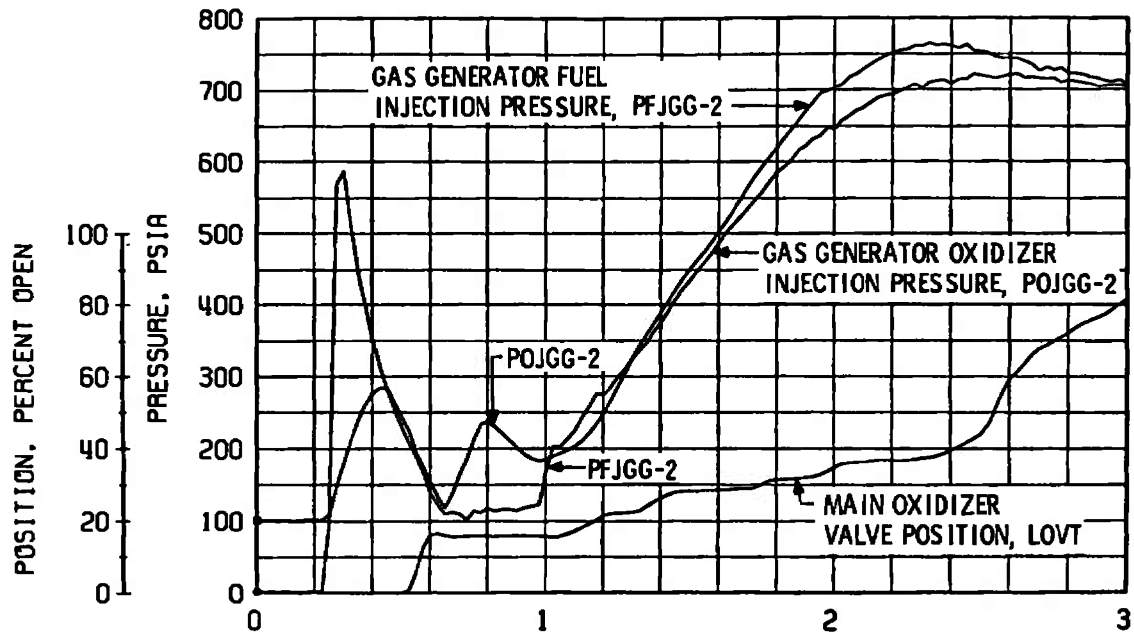


a. Start Transient, Thrust Chamber Fuel System

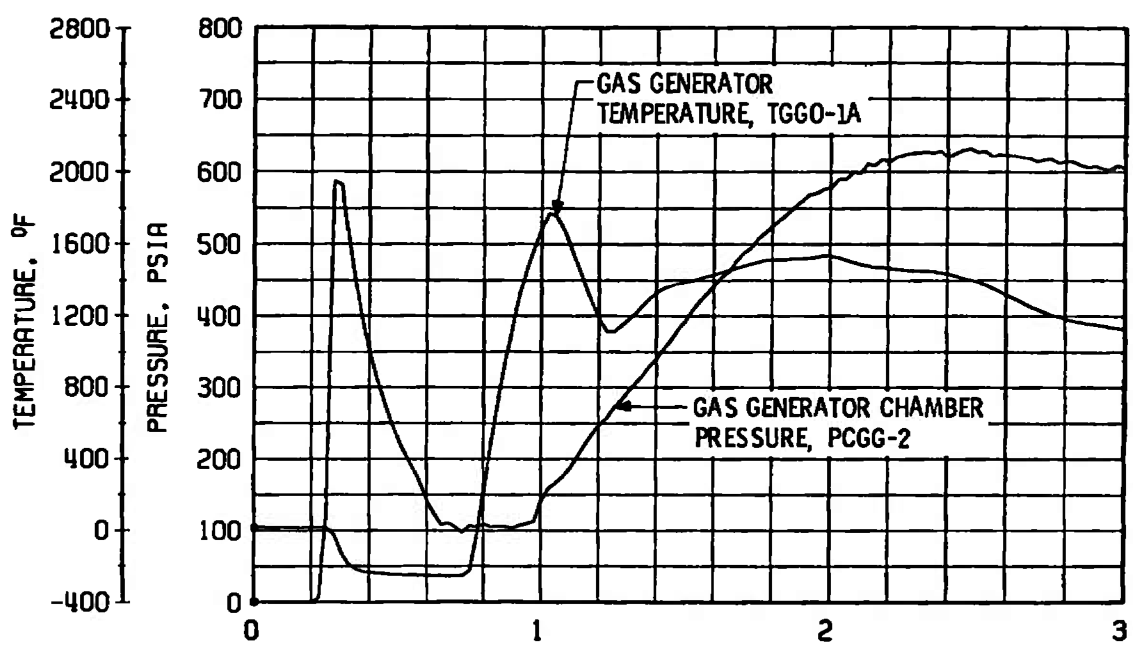


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 32 Engine Start and Shutdown Transients, Firing 22B

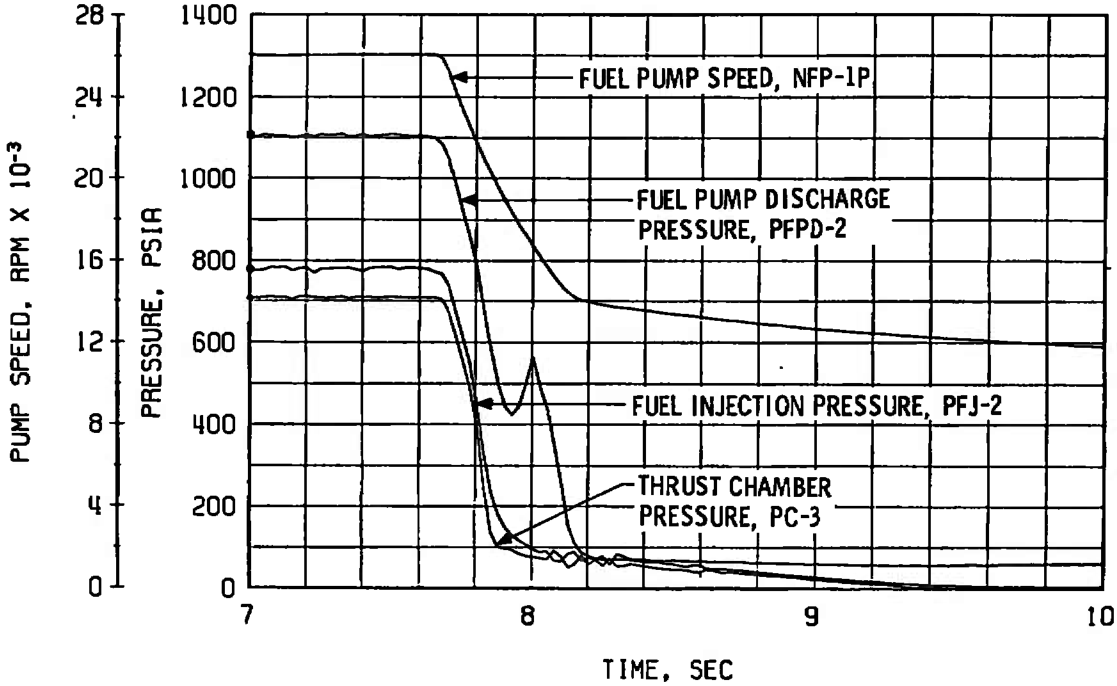


c. Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position

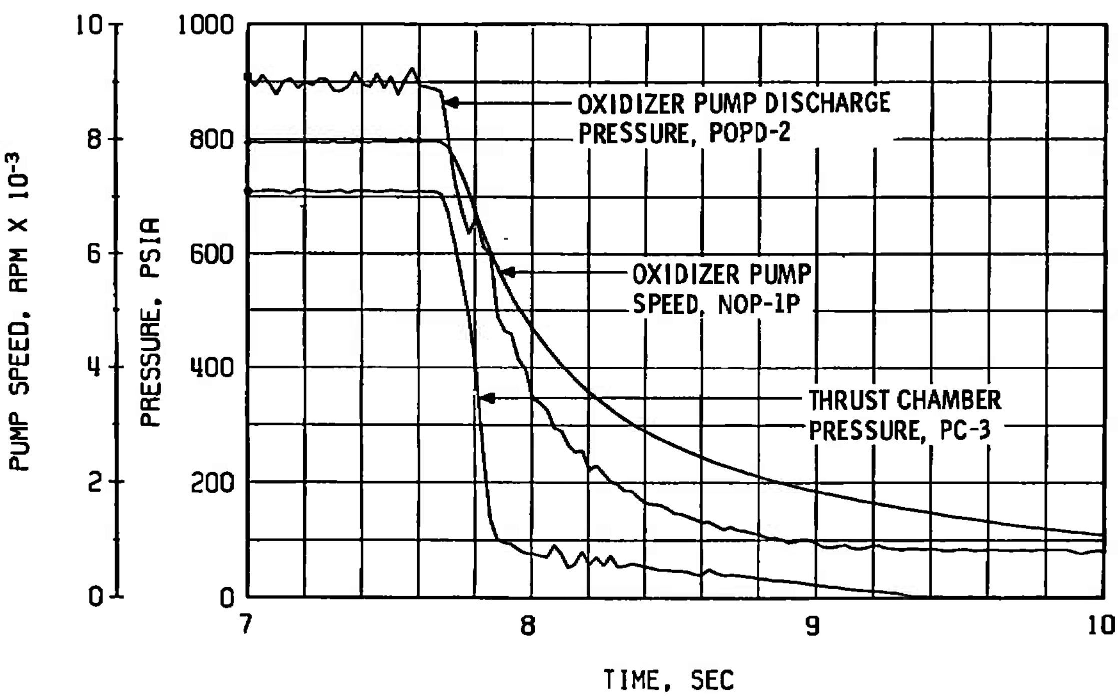


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 32 Continued

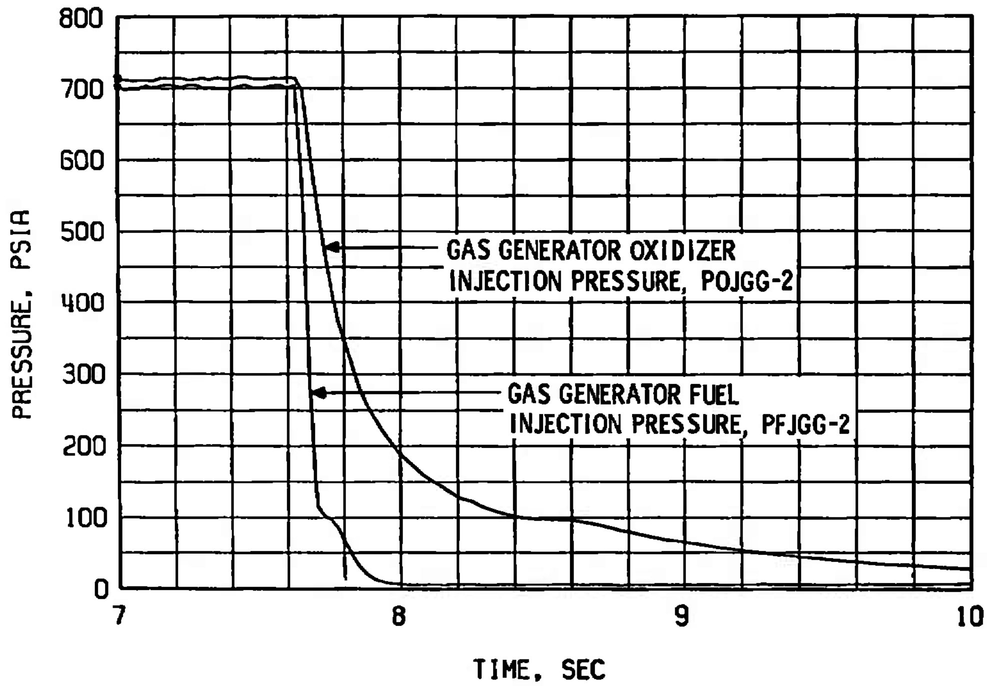


e. Shutdown Transient, Thrust Chamber Fuel System

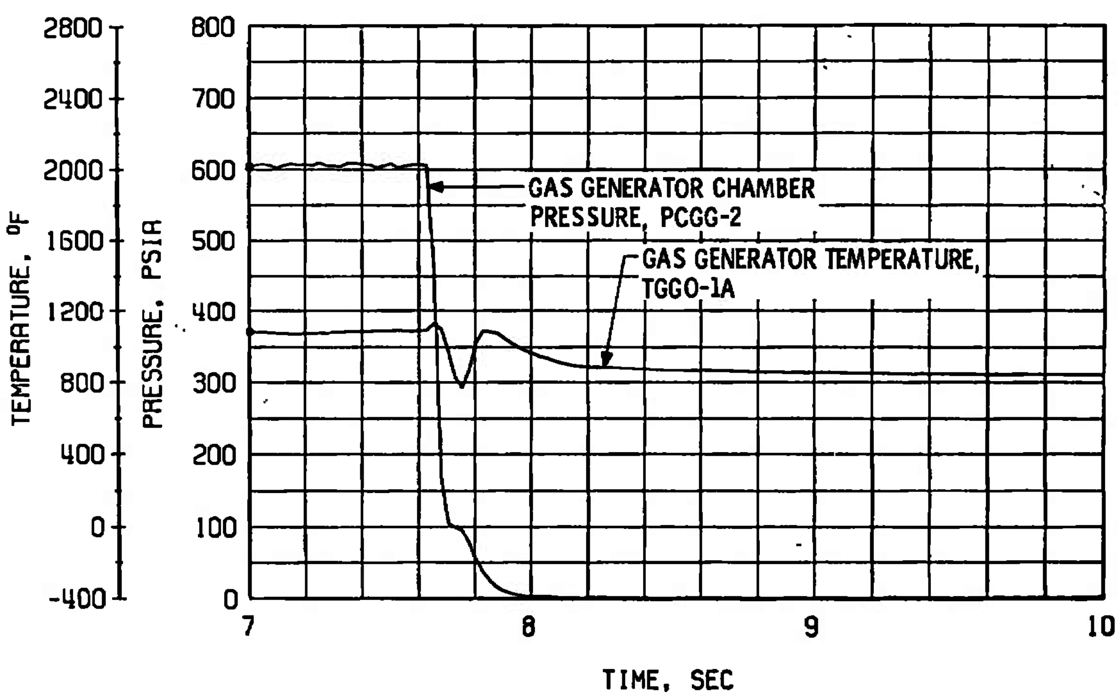


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 32 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 32 Concluded

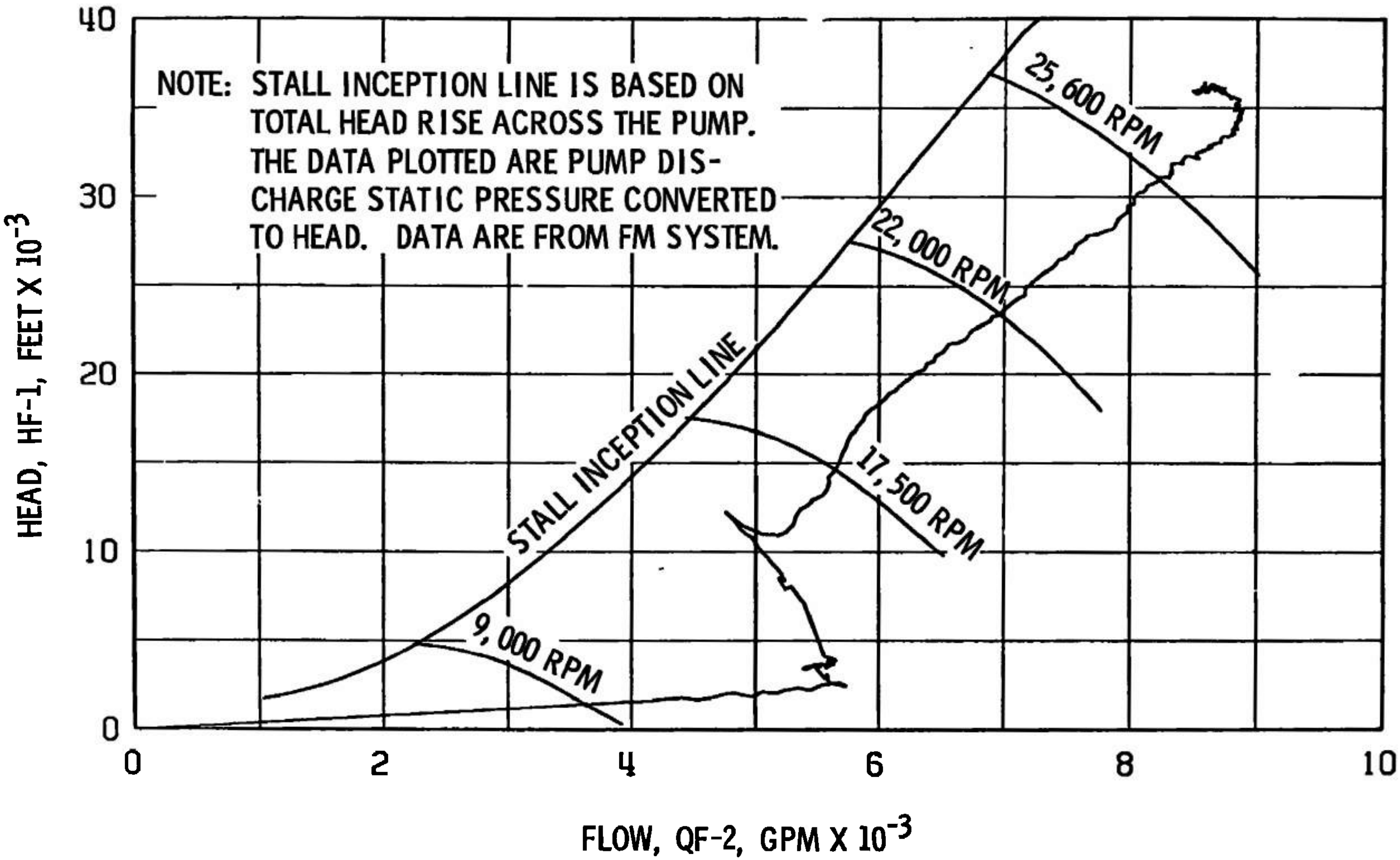
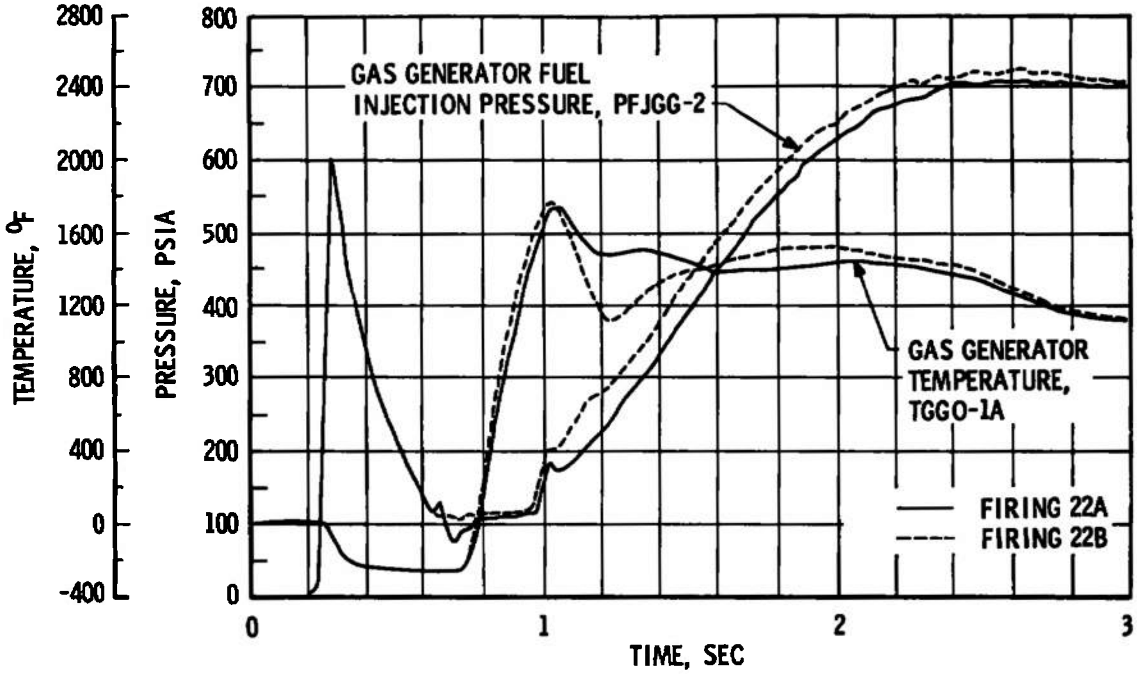
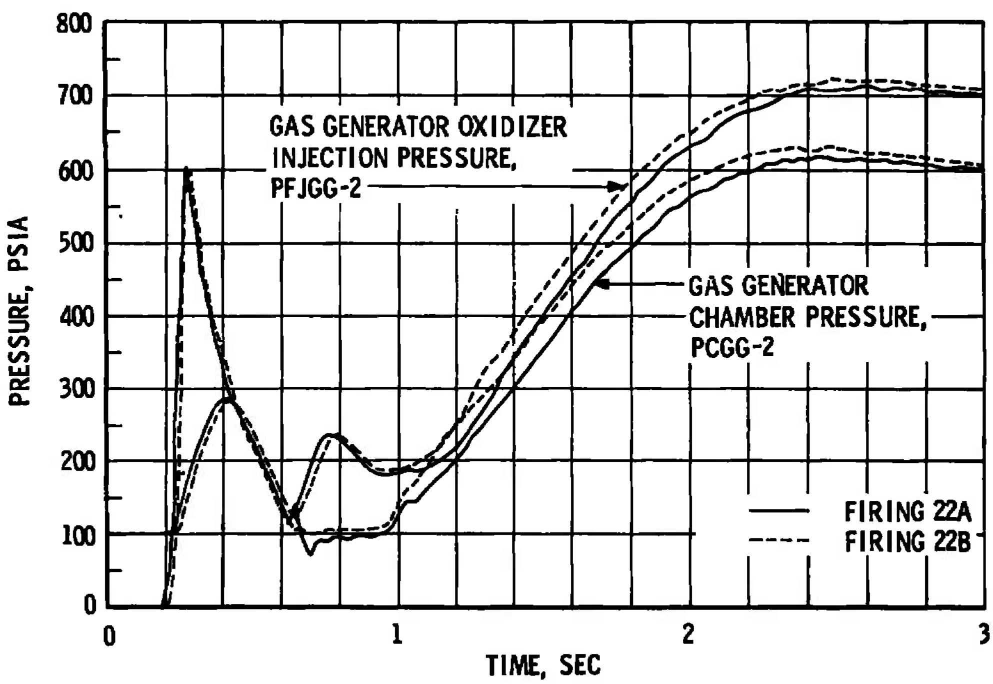


Fig. 33 Fuel Pump Transient Performance, Firing 22B

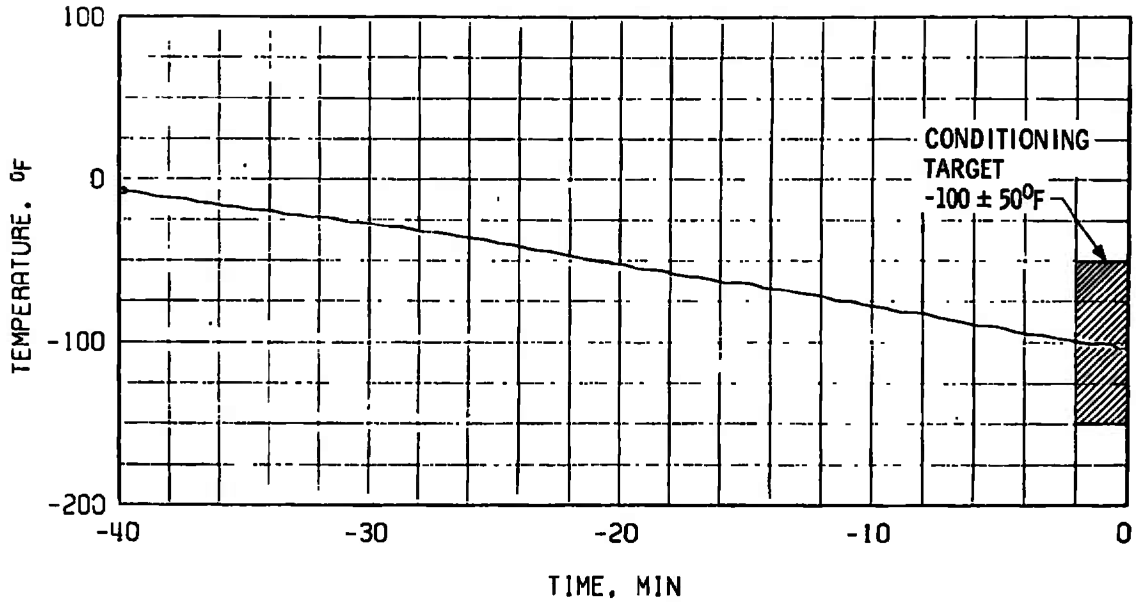


a. Gas Generator Fuel Injection Pressure and Gas Generator Temperature

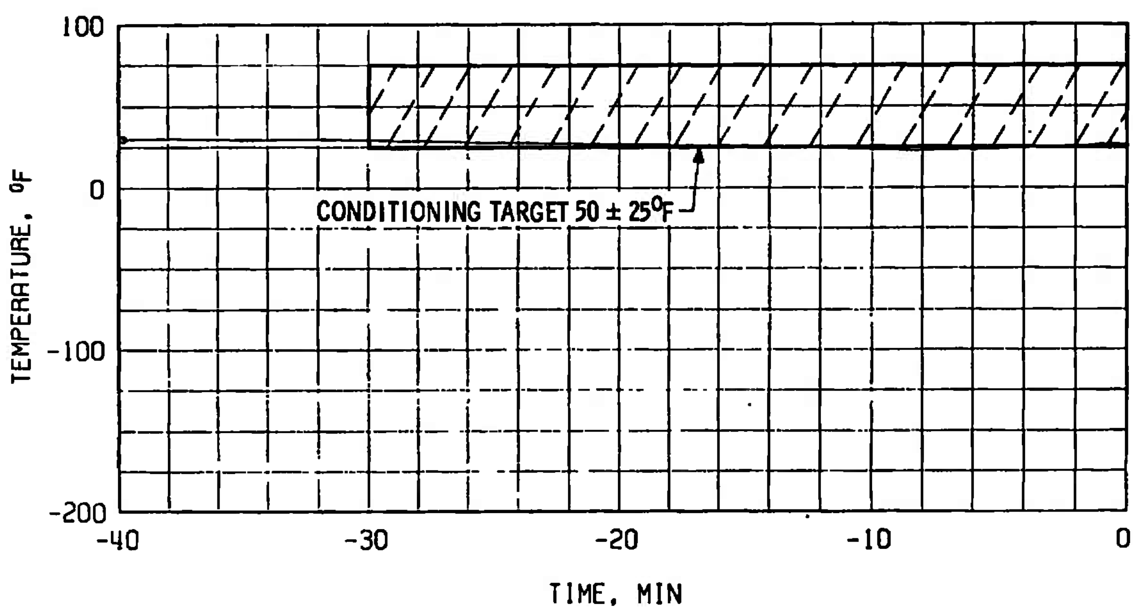


b. Gas Generator Oxidizer Injection and Chamber Pressure

Fig. 34 Gas Generator Transient Comparison, Firings 22A and 22B

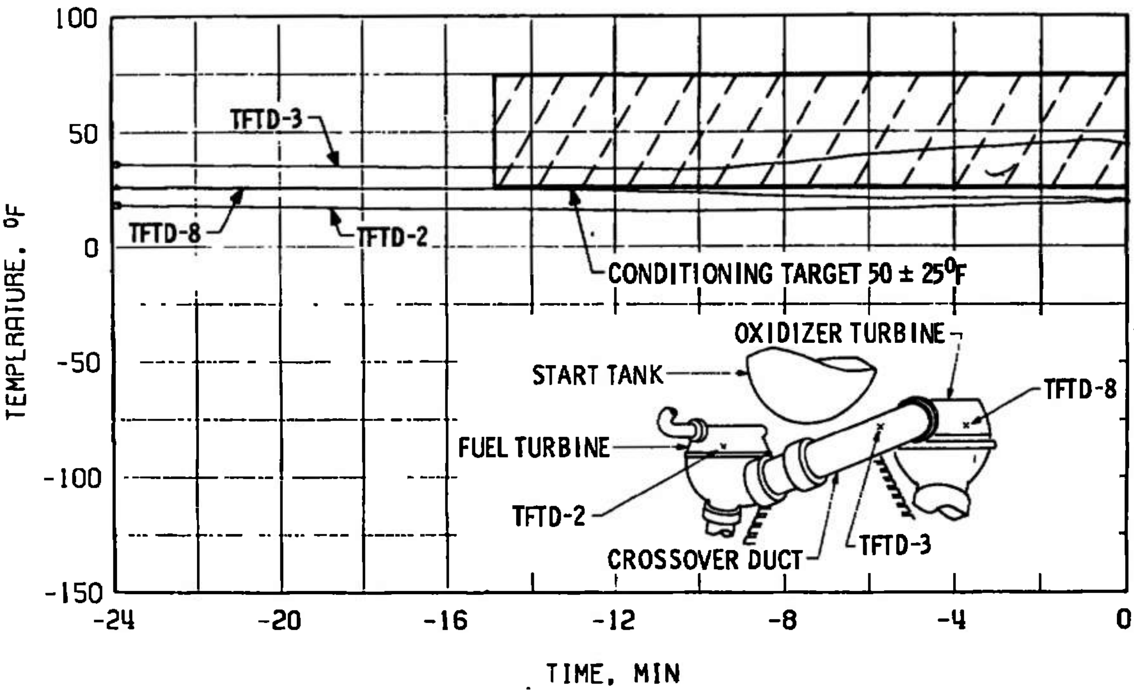


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

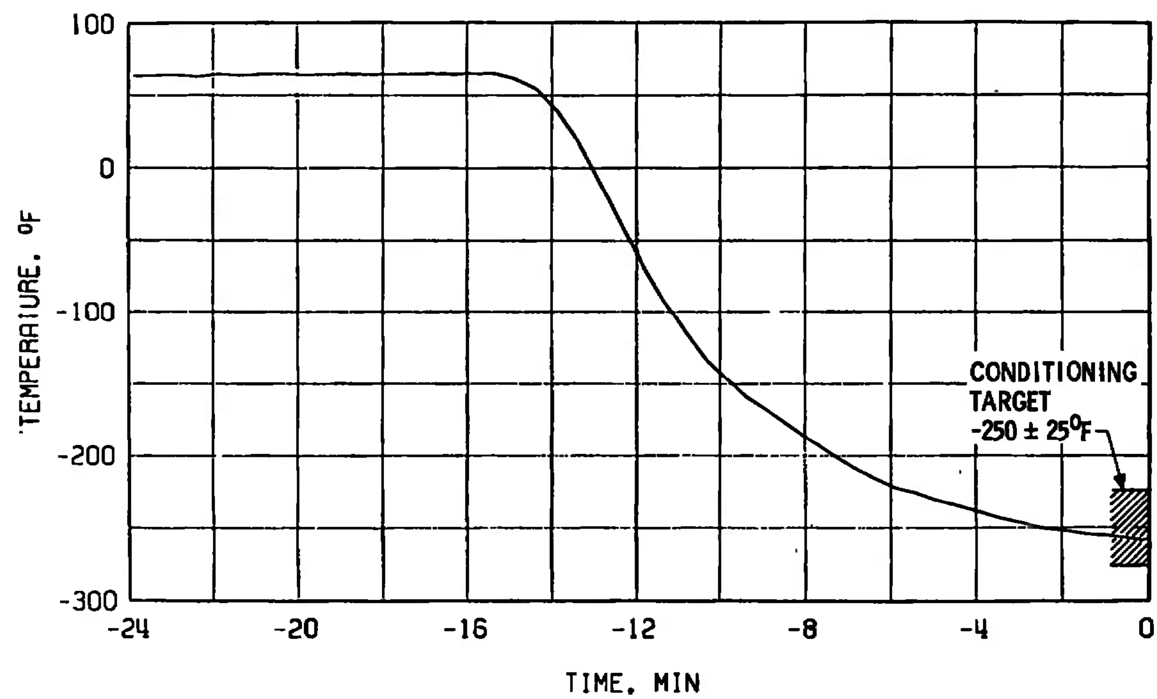


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 35 History of Firing 22C Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3, and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 35 Concluded

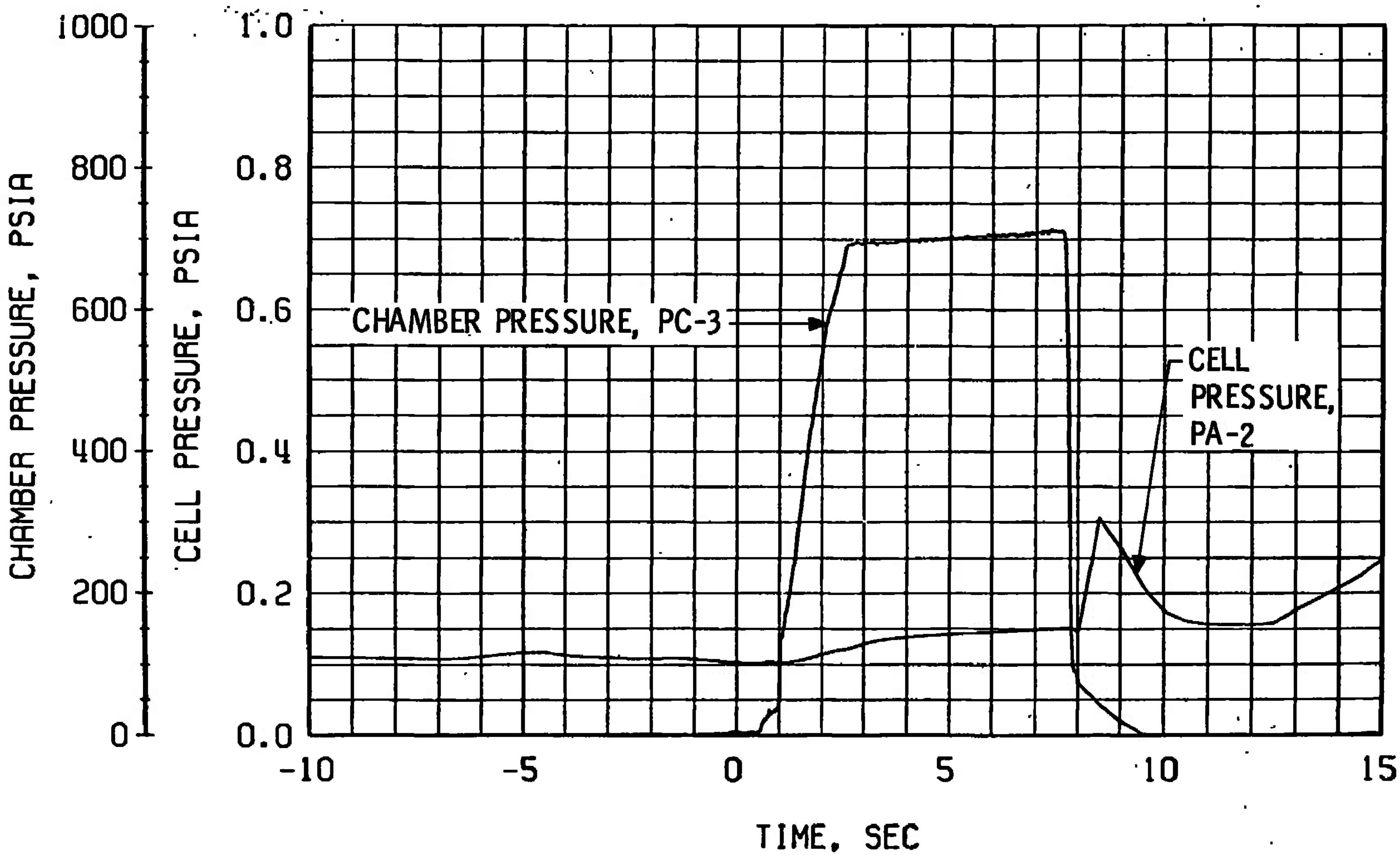
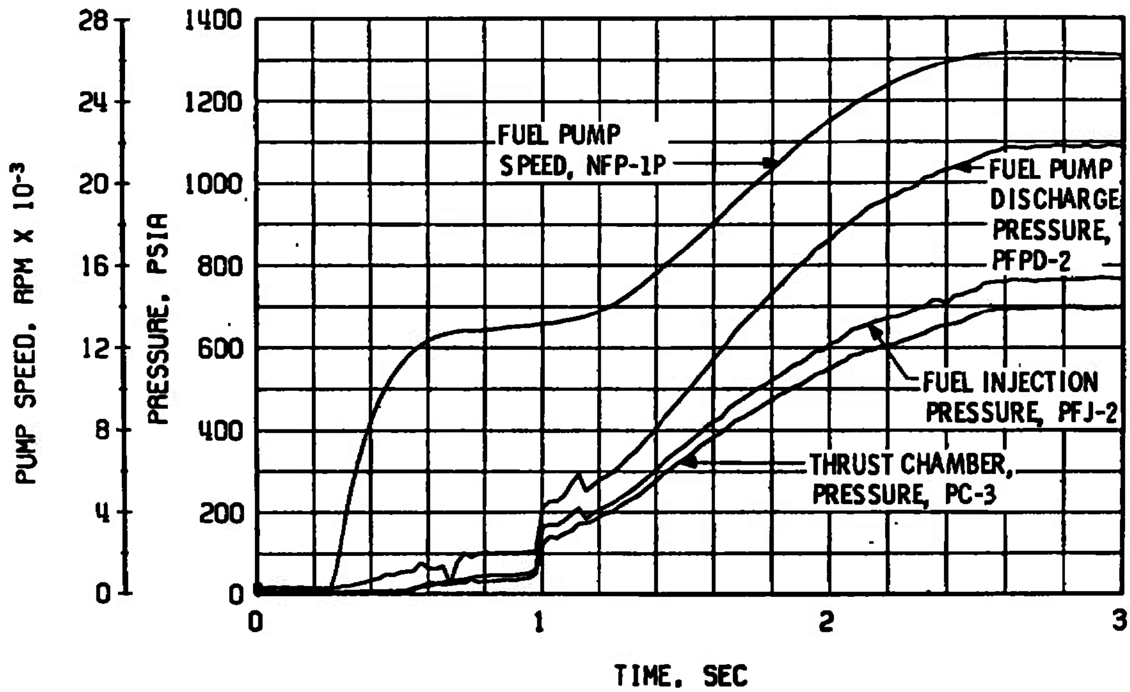
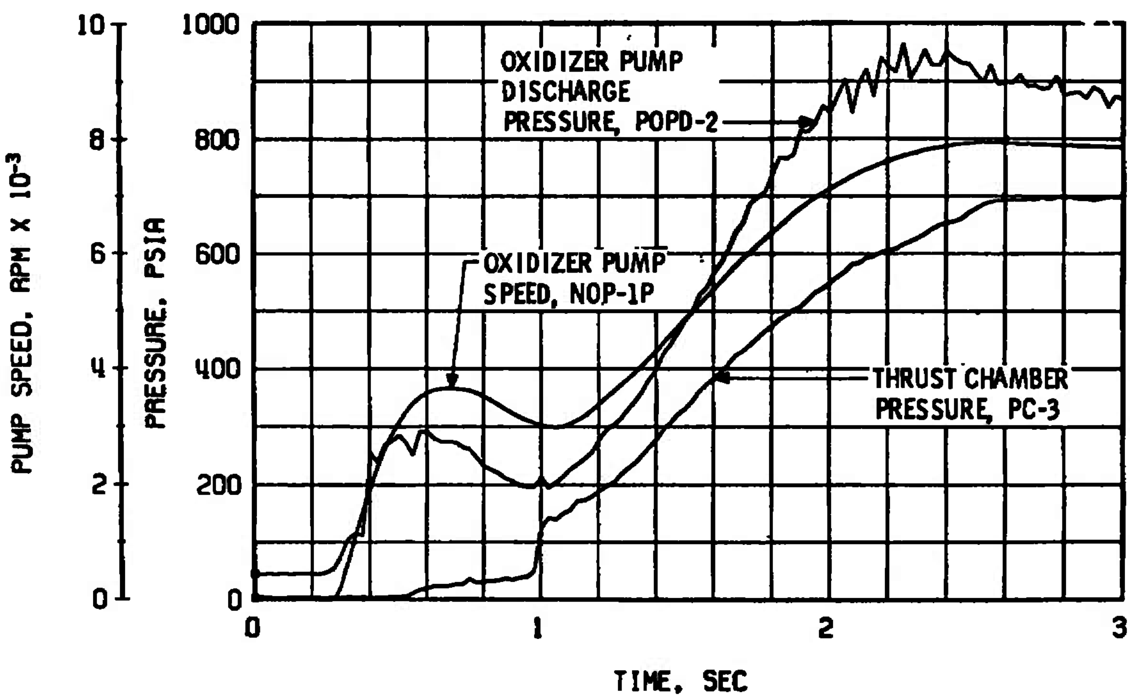


Fig. 36 Engine Chamber and Test Cell Pressure, Firing 22C

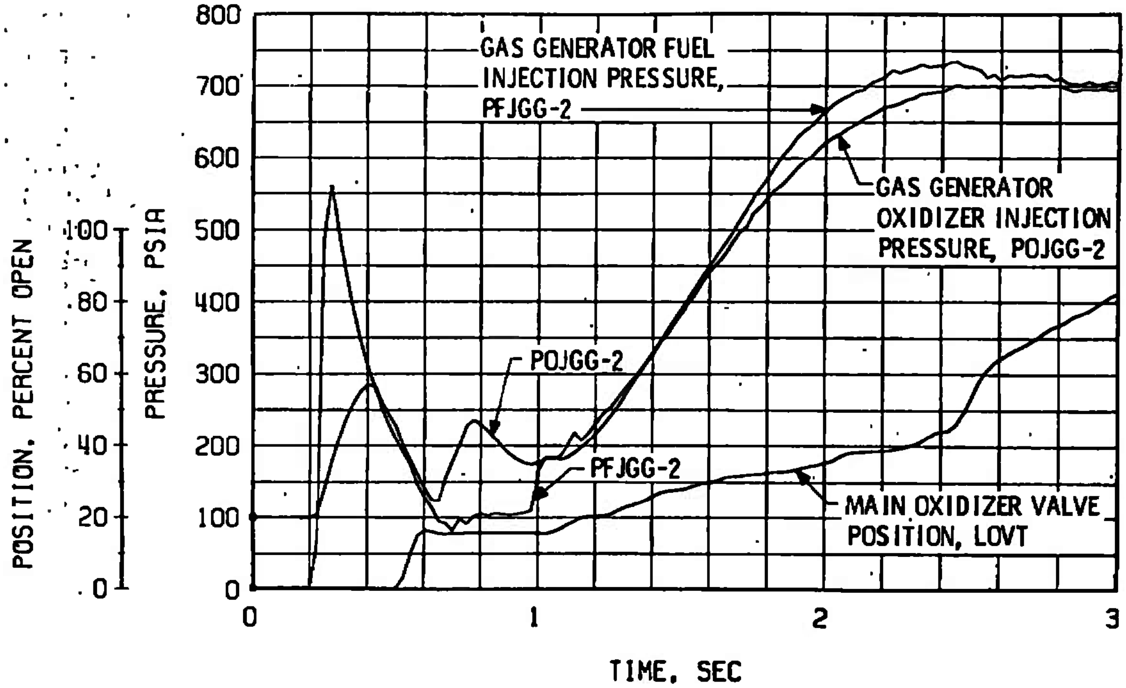


a. Start Transient, Thrust Chamber Fuel System

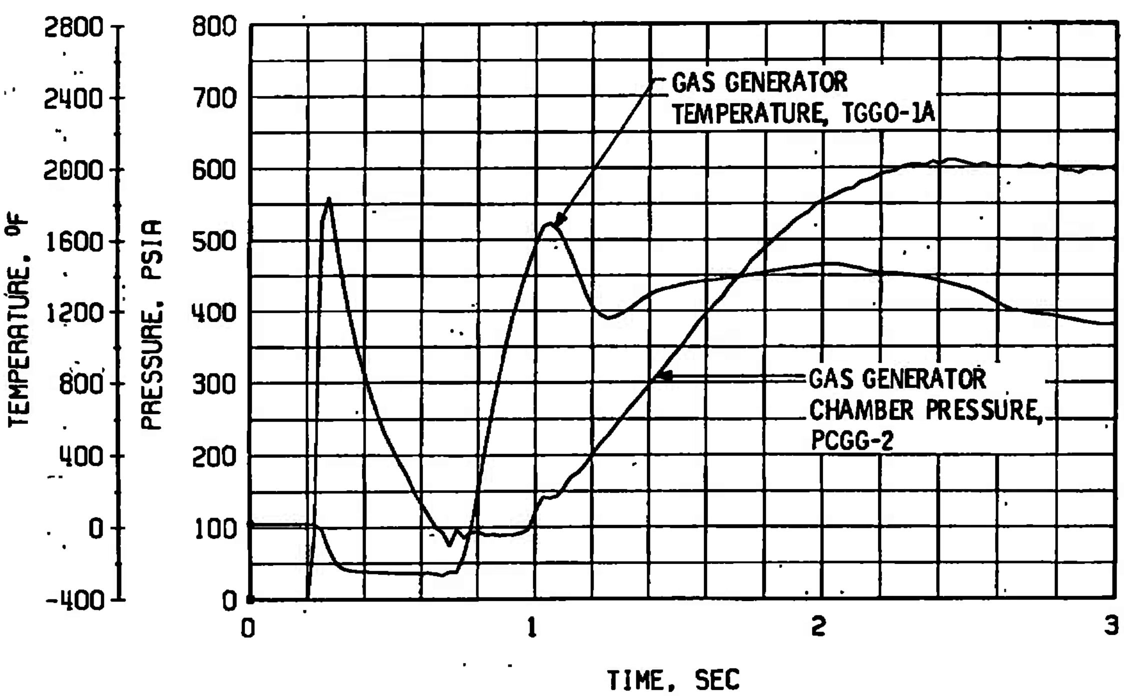


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 37 Engine Start and Shutdown Transients, Firing 22C

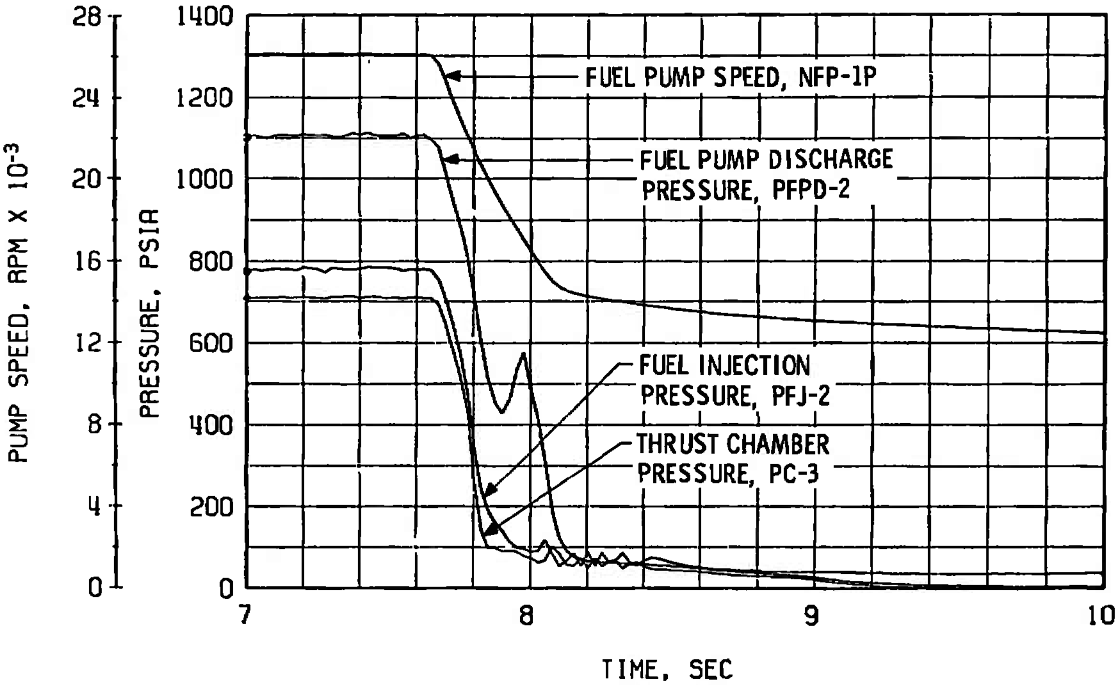


c. Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position

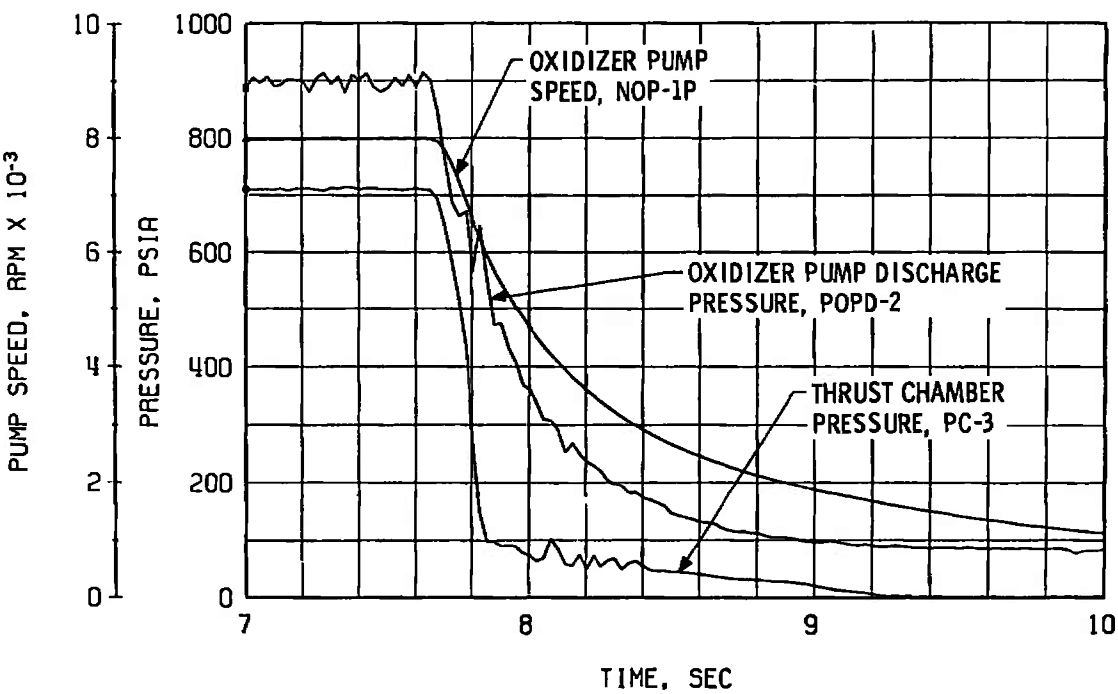


d. Start Transient, Gas Generator Temperature and Chamber Pressure

Fig. 37 Continued

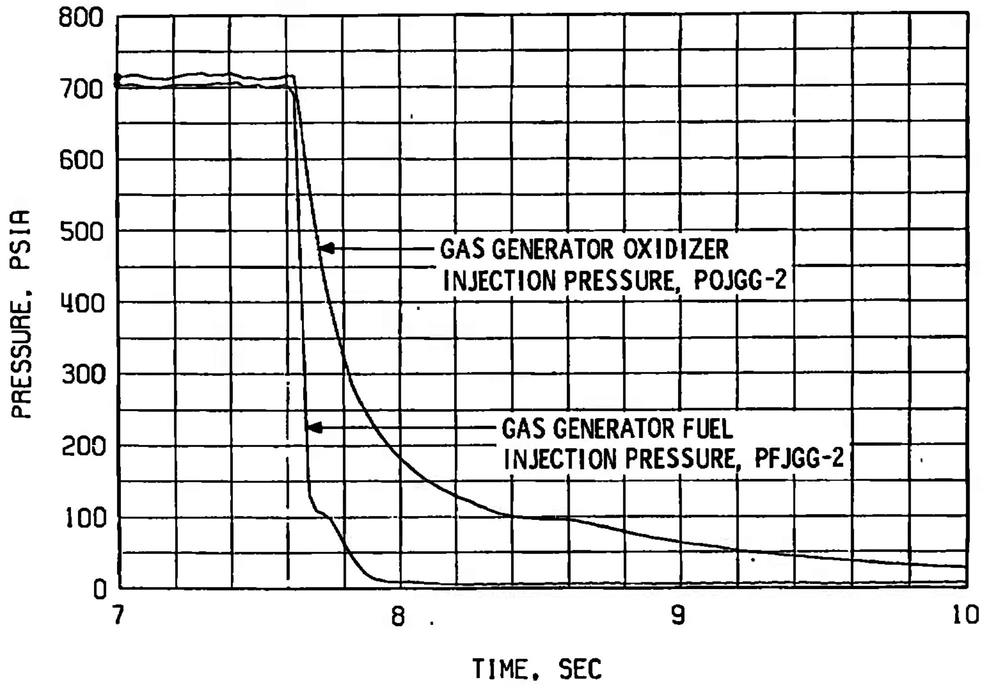


e. **Shutdown Transient, Thrust Chamber Fuel System**

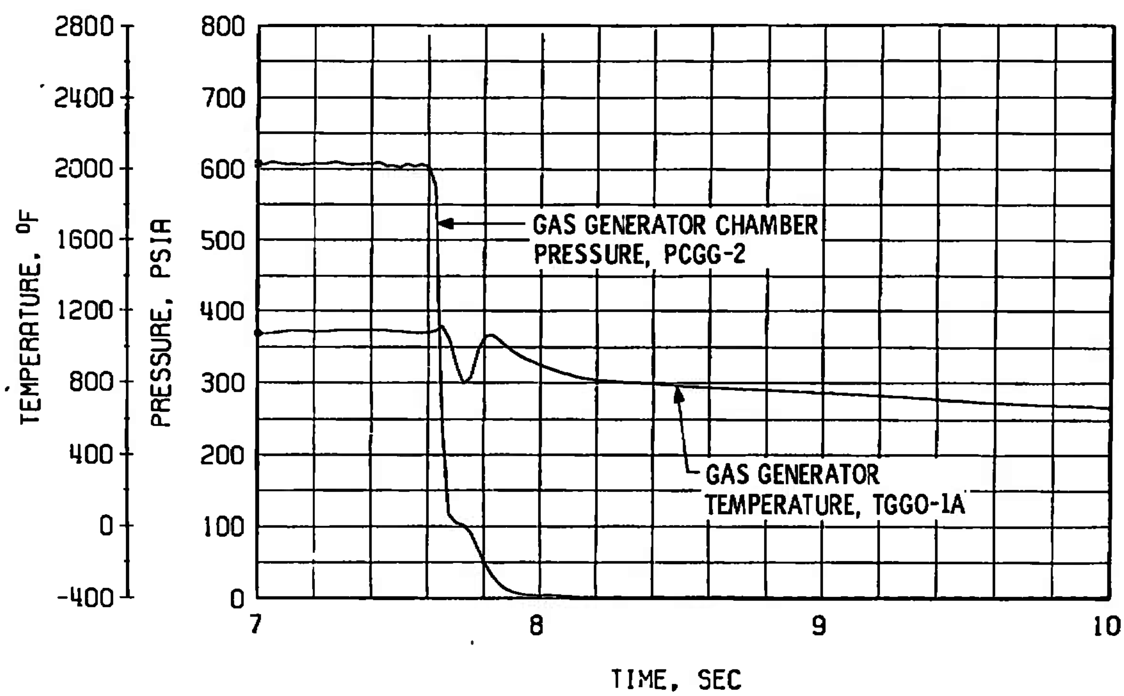


f. **Shutdown Transient, Thrust Chamber Oxidizer System**

Fig. 37 Continued



g. Shutdown Transient, Gas Generator Injection Pressures



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressure

Fig. 37 Concluded

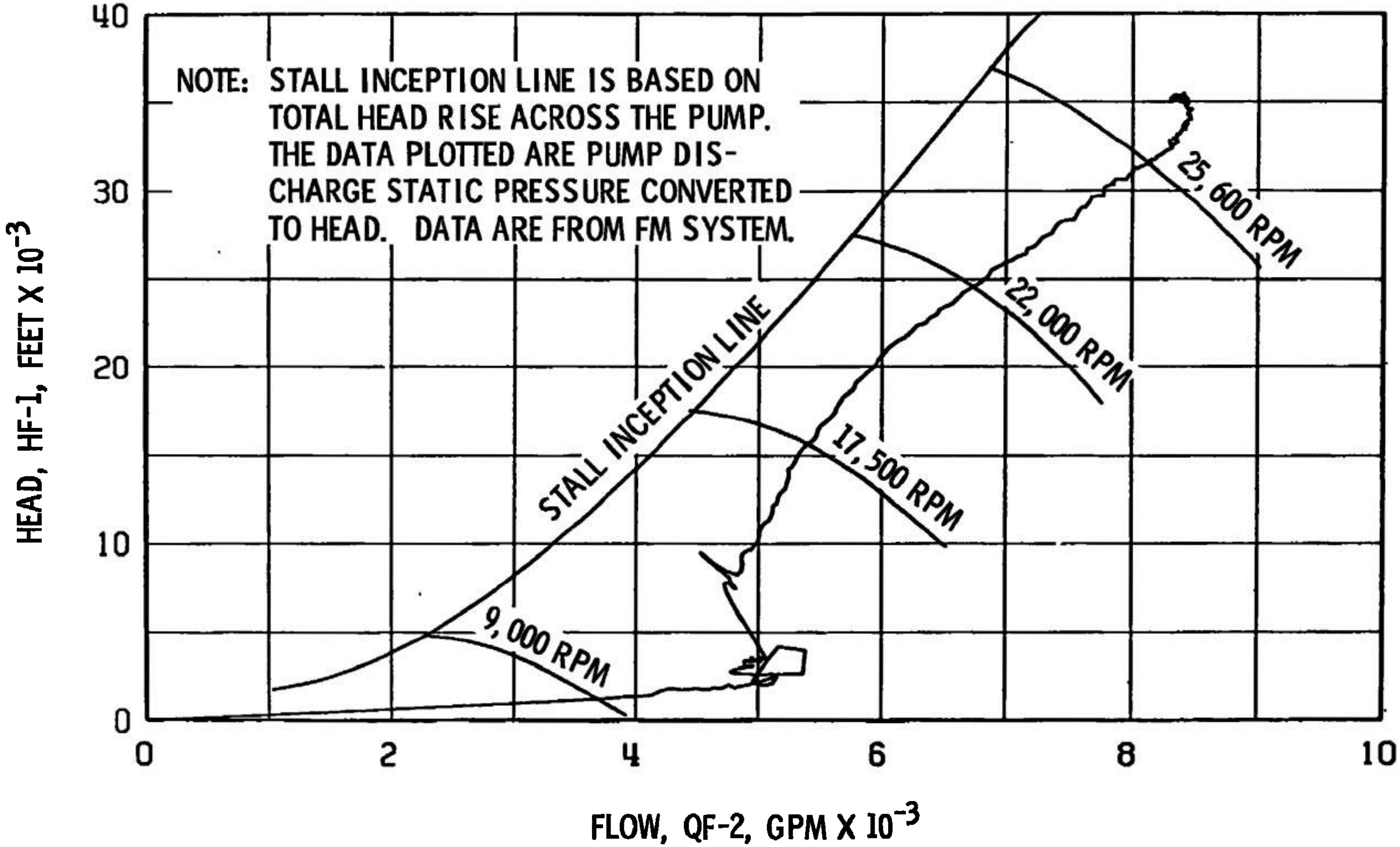
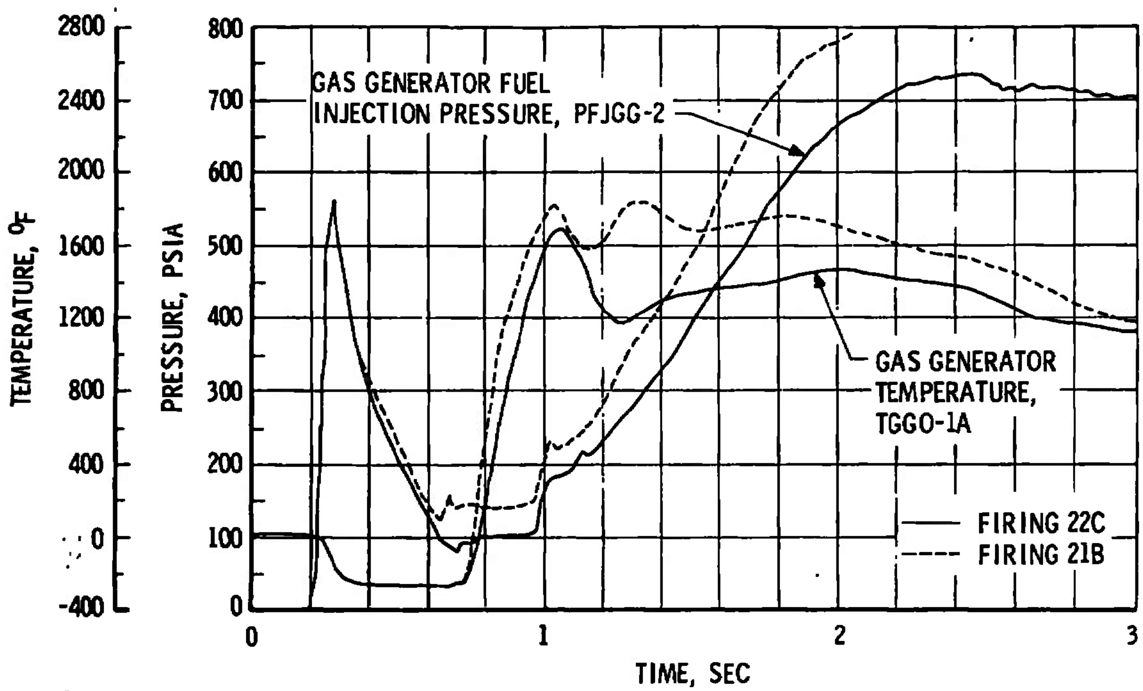
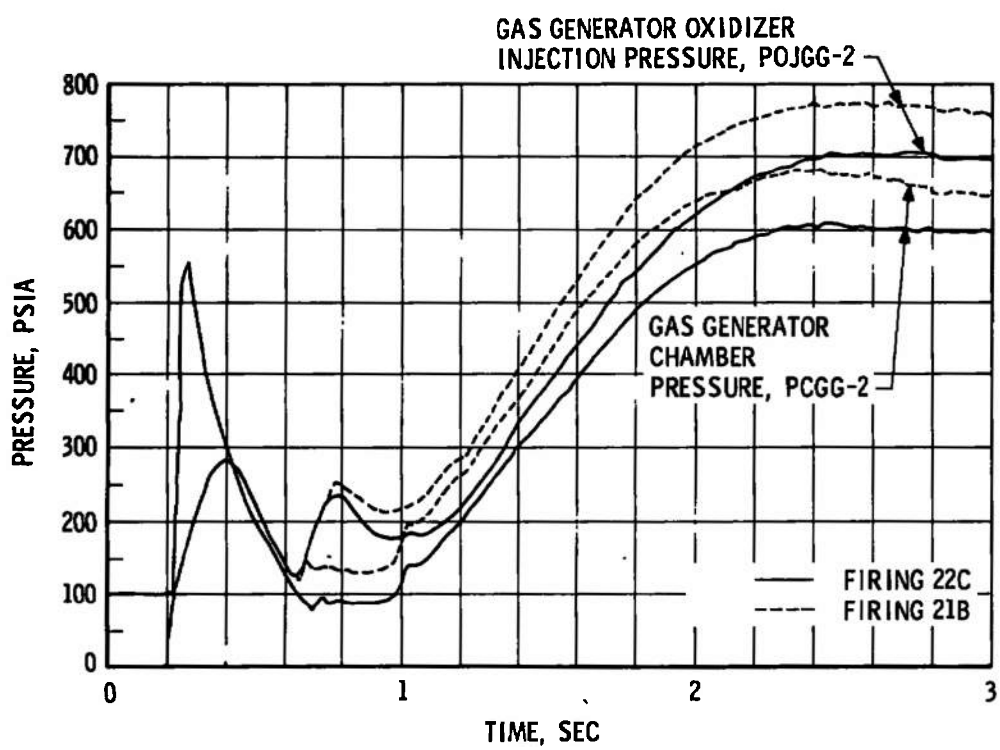


Fig. 38 Fuel Pump Transient Performance, Firing 22C

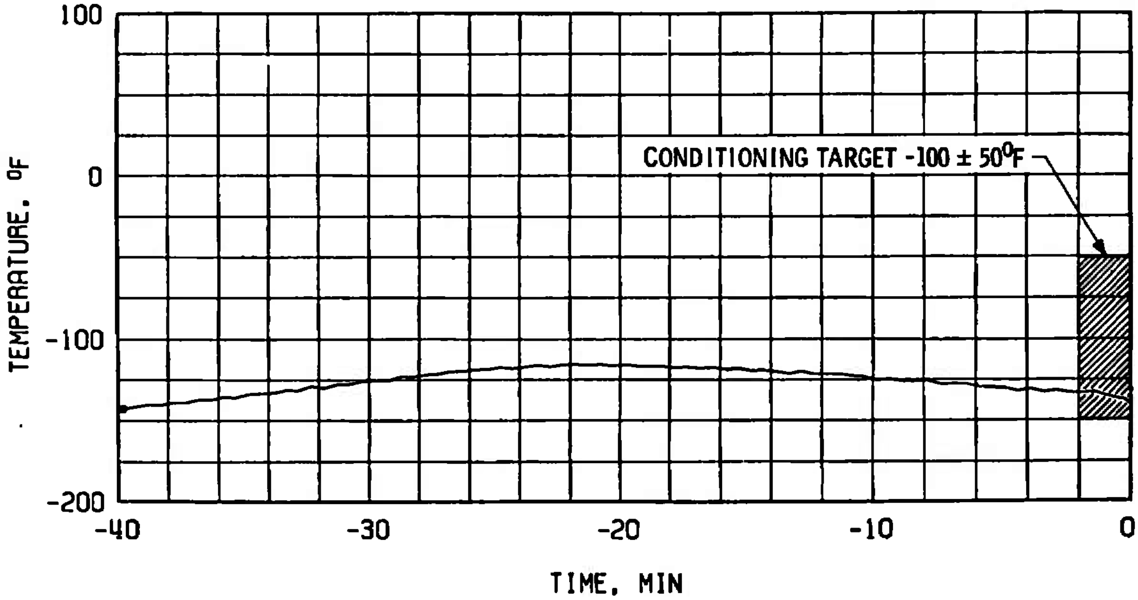


a. Gas Generator Fuel Injection Pressure and Gas Generator Temperature

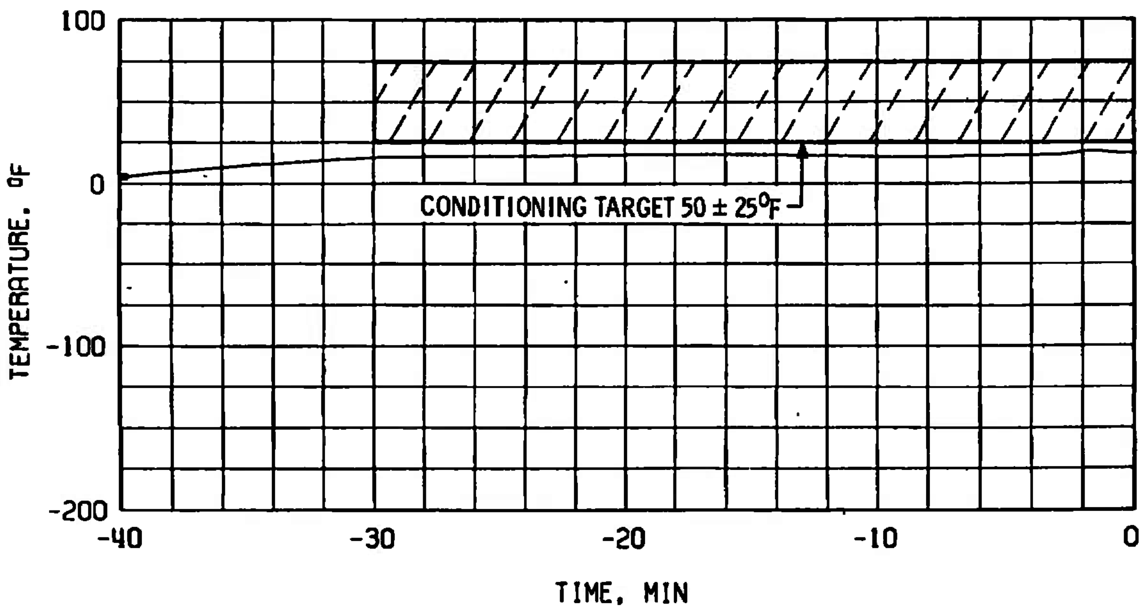


b. Gas Generator Oxidizer Injection and Chamber Pressures

Fig. 39 Gas Generator Transient Comparisons, Firings 22C and 21B

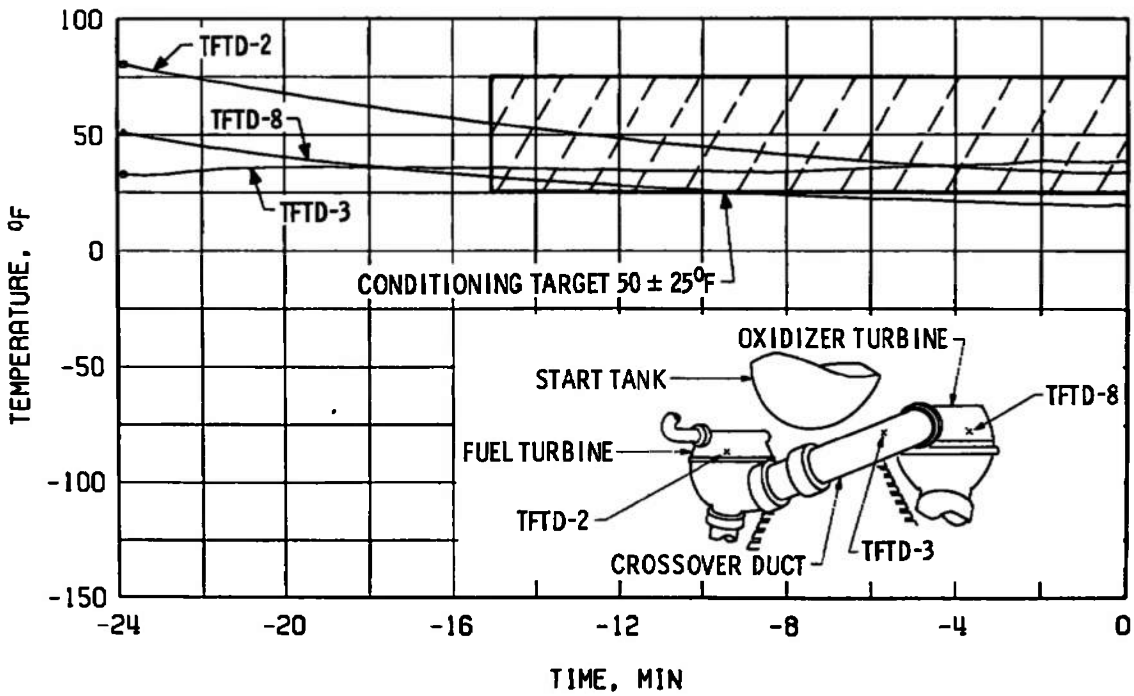


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

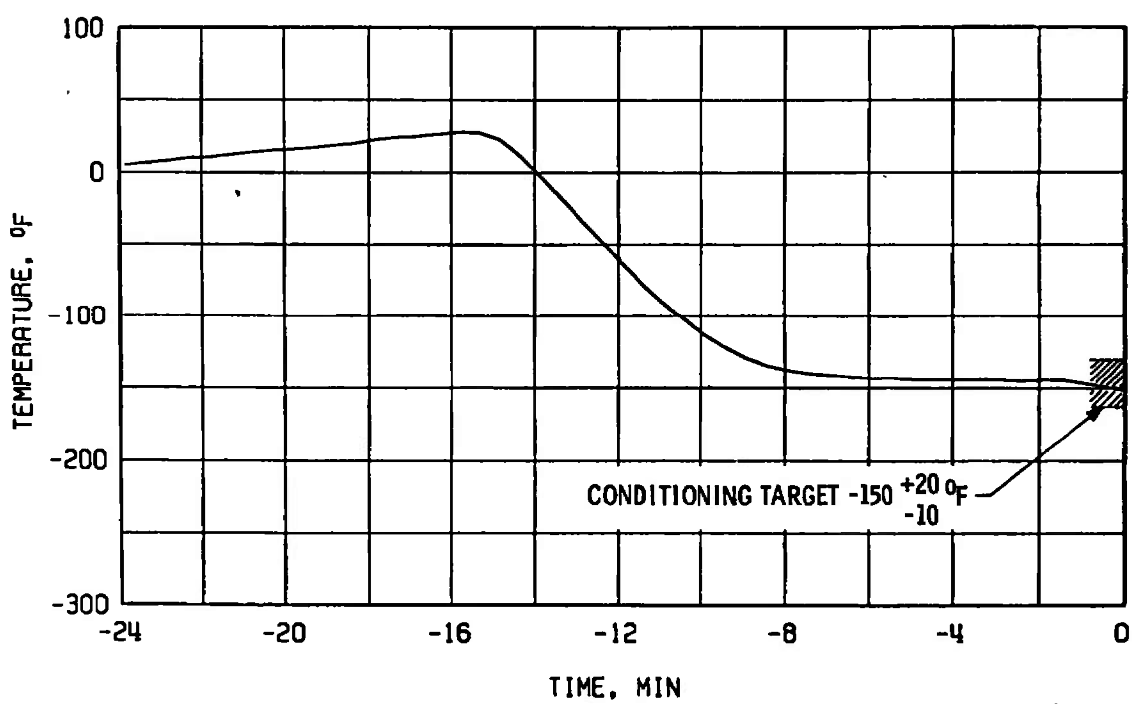


b. Start Tank Discharge Valve Opening Control Line, TSTDVOC

Fig. 40 History of Firing 22D Pre-Fire Temperature Conditioning



c. Crossover Duct, TFTD-2, -3 and -8



d. Thrust Chamber Temperature, TTC-1P

Fig. 40 Concluded

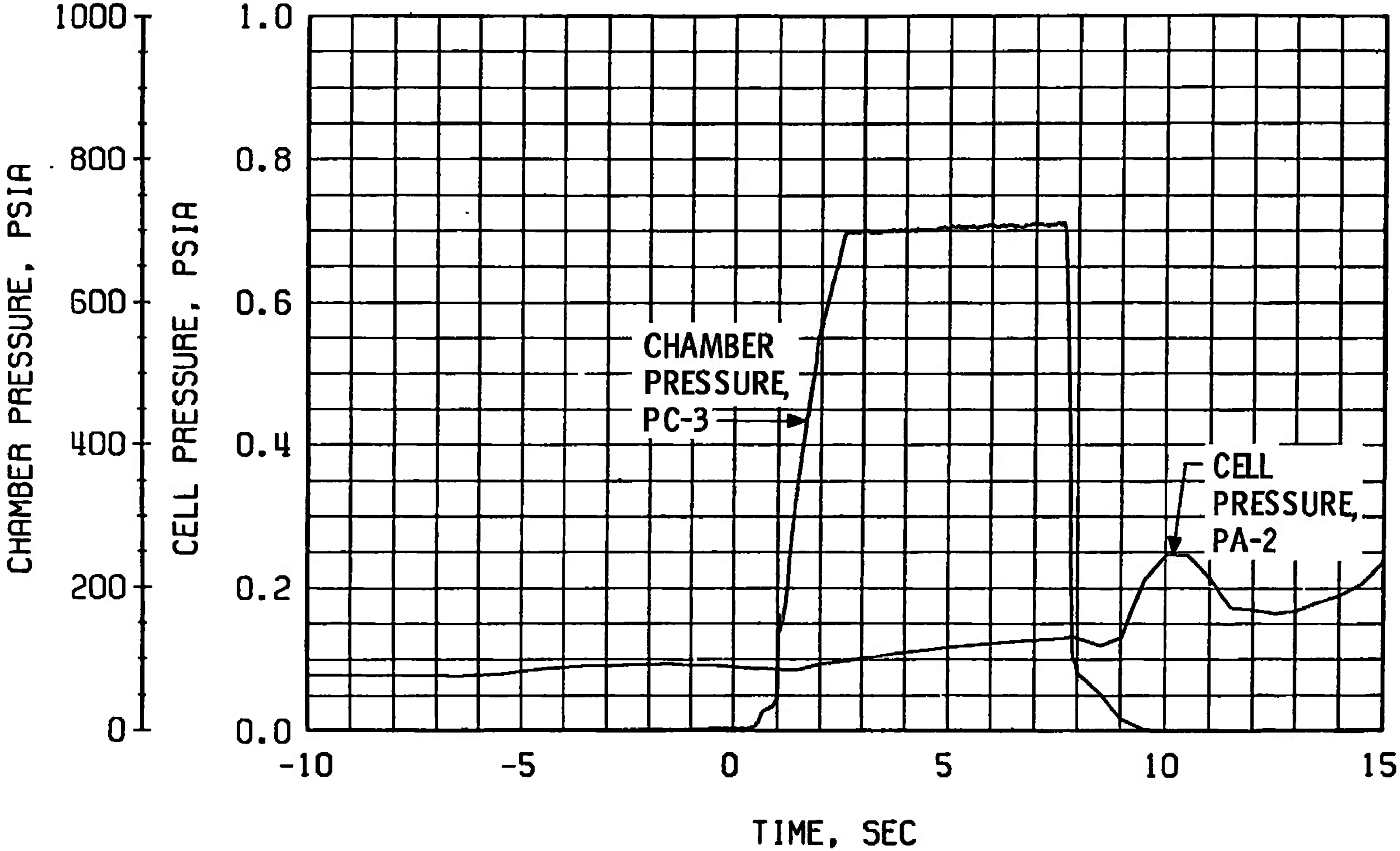
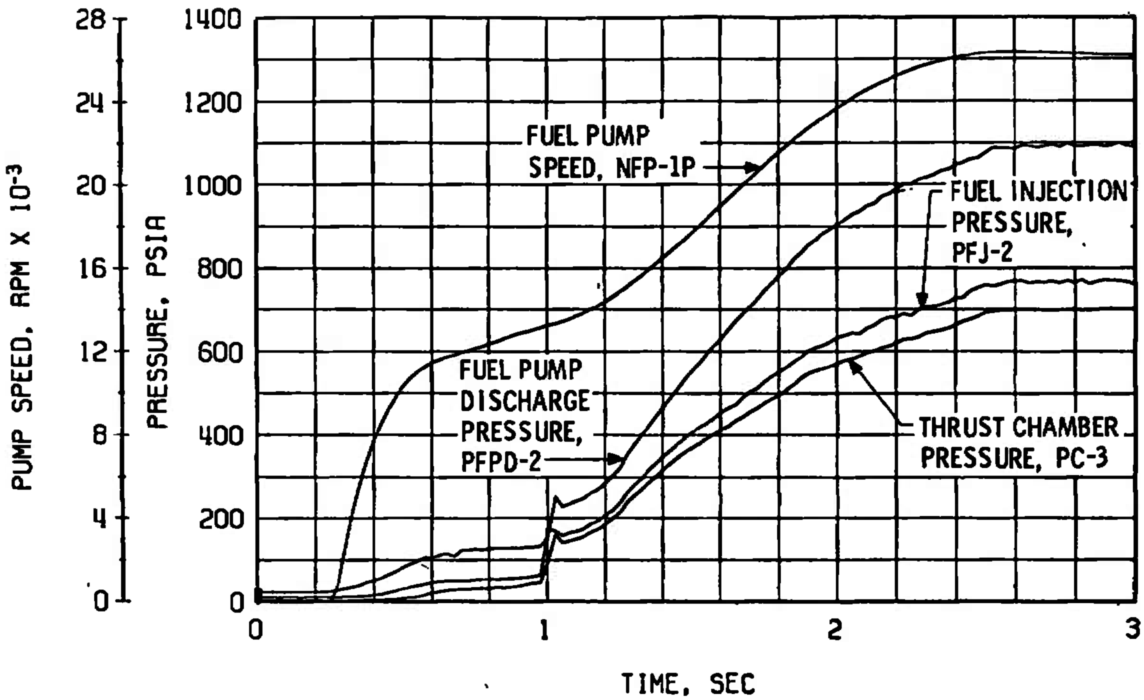
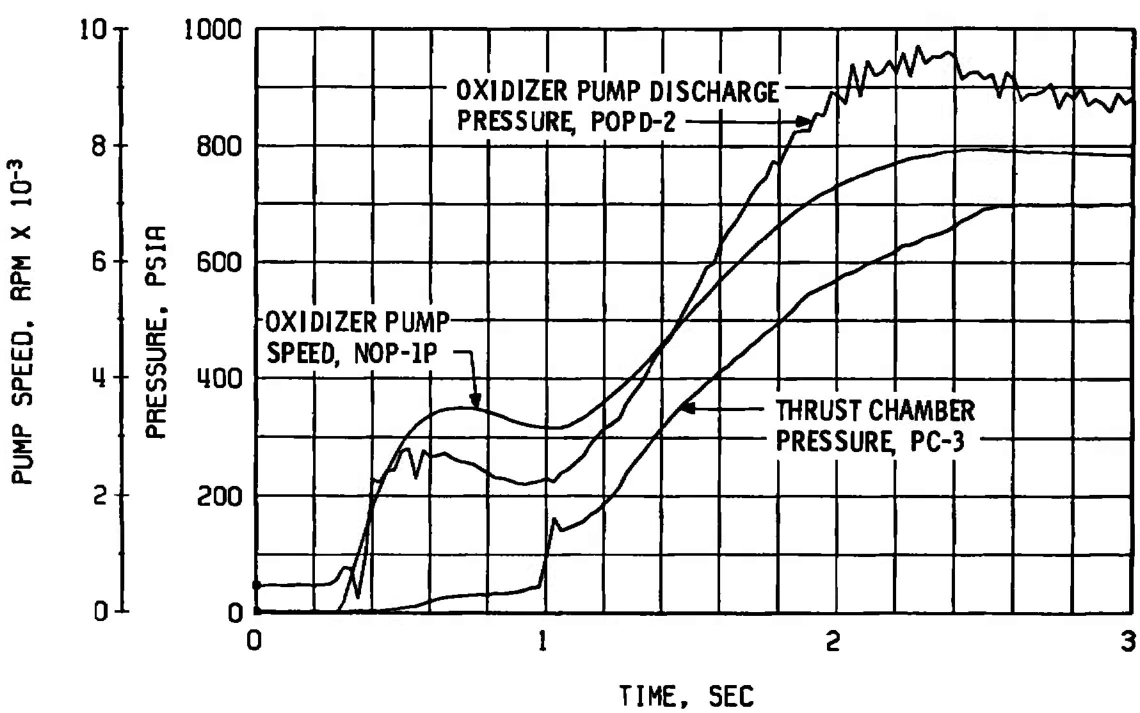


Fig. 41 Engine Chamber and Test Cell Pressure, Firing 22D

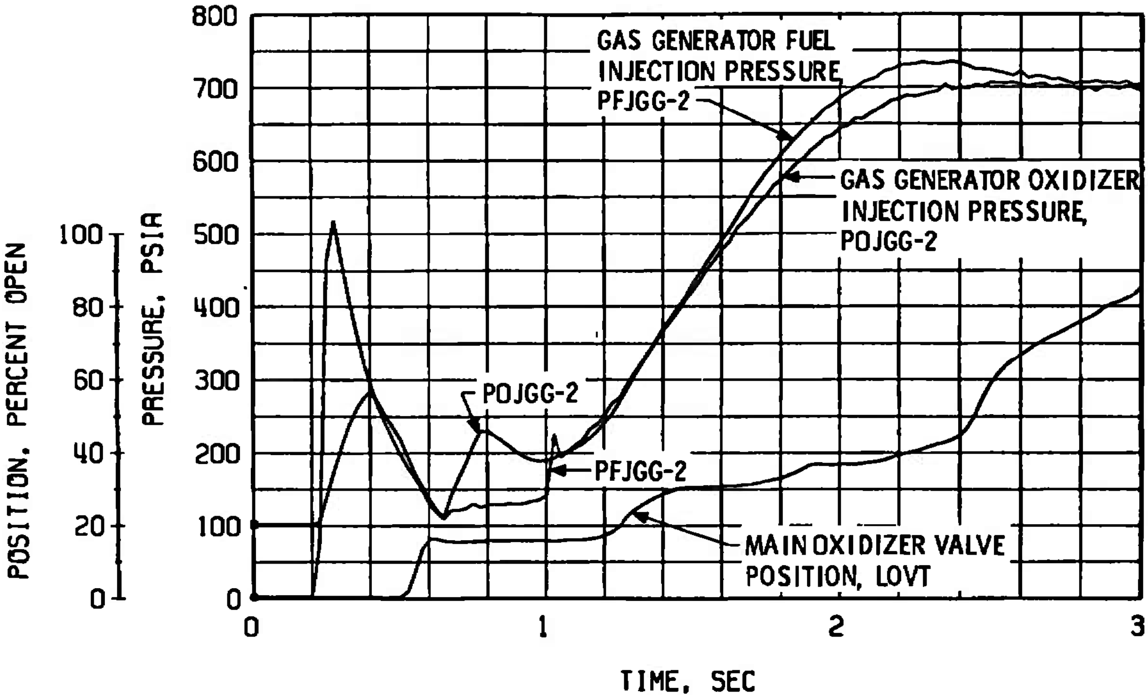


a. Start Transient, Thrust Chamber Fuel System

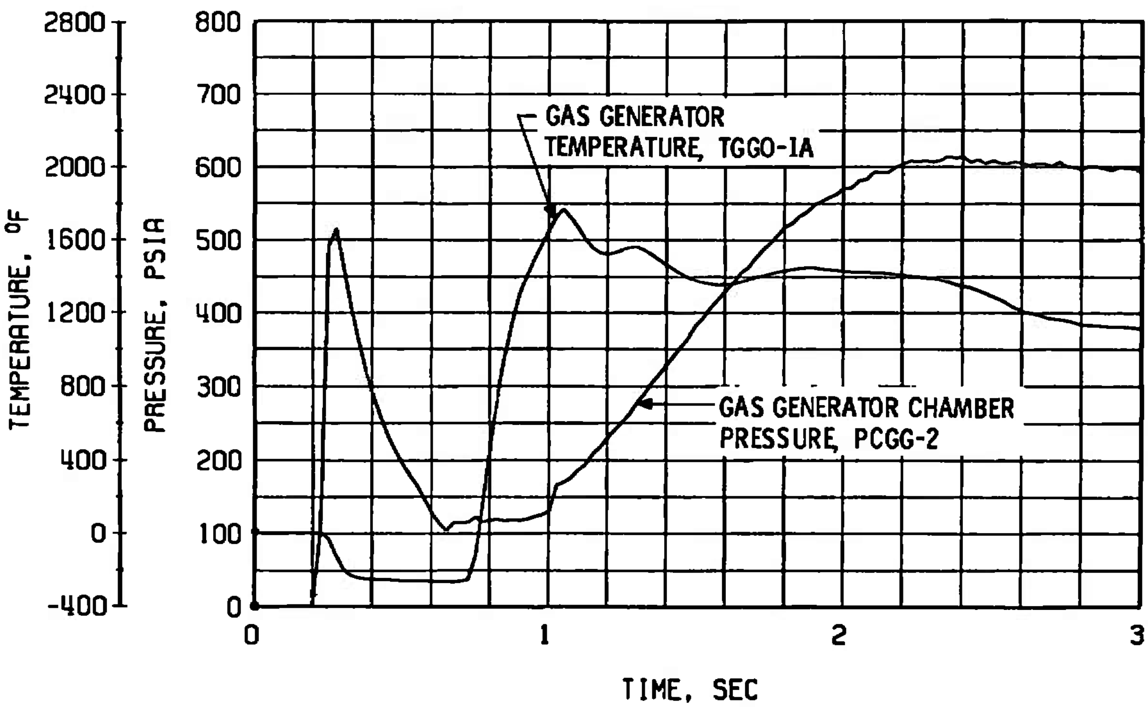


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 42 Engine Start and Shutdown Transients, Firing 22D

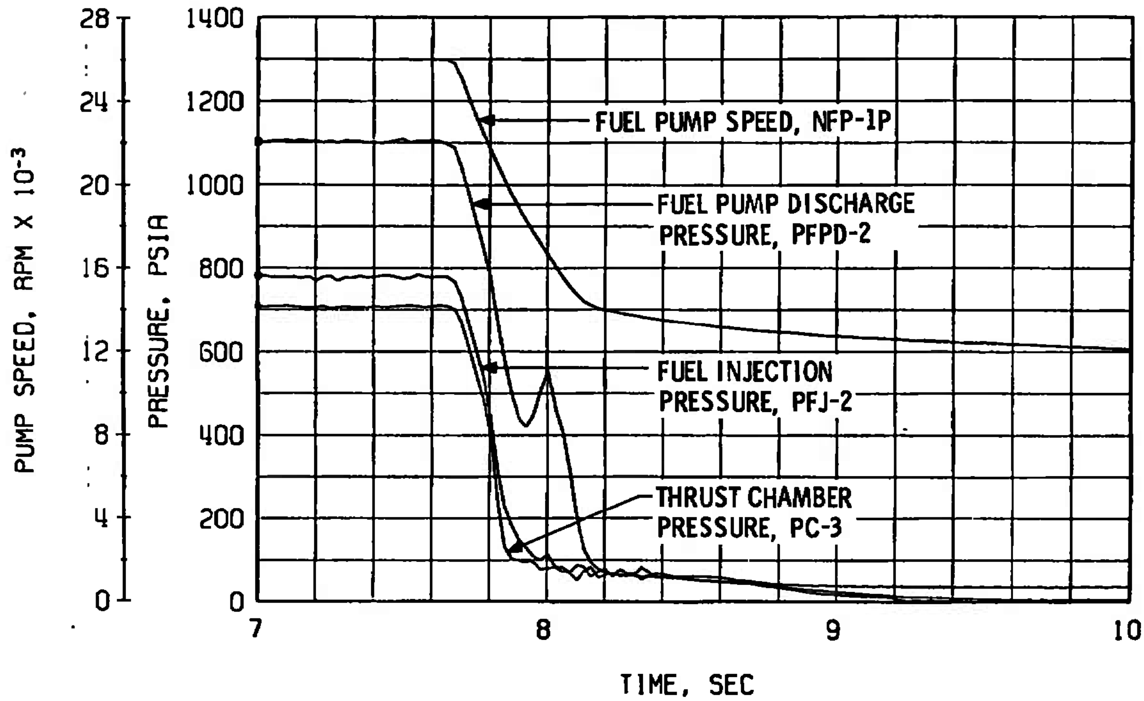


c. **Start Transient, Gas Generator Injection Pressures and Main Oxidizer Valve Position**

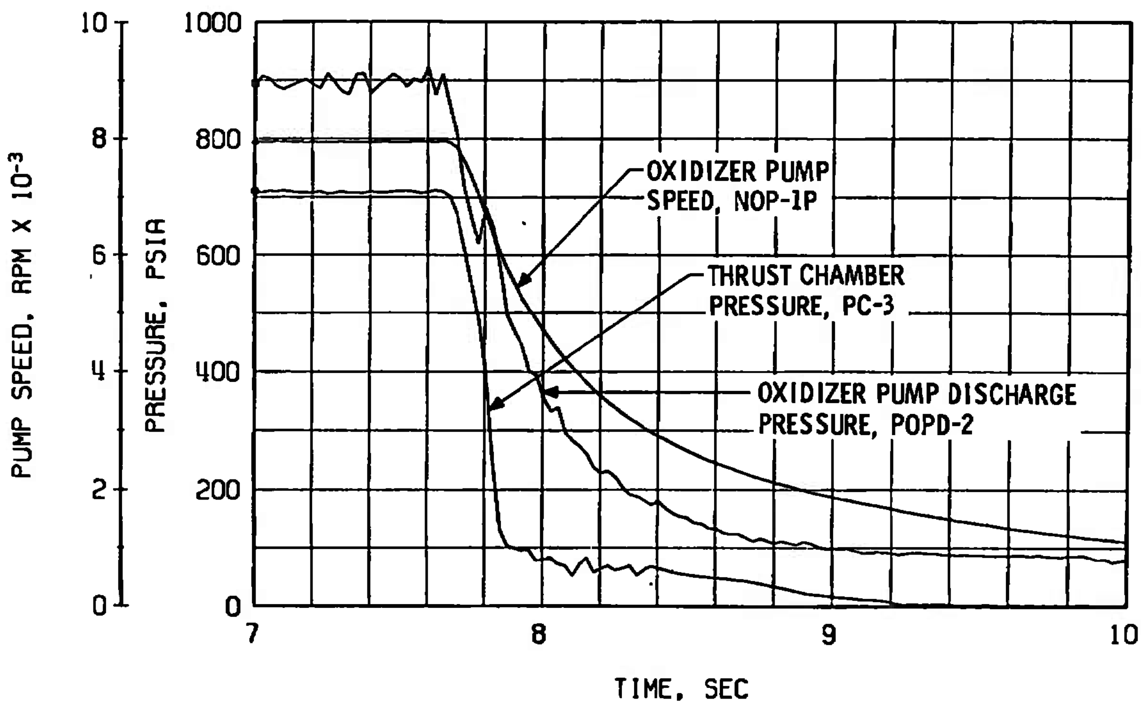


d. **Start Transient, Gas Generator Temperatures and Chamber Pressure**

Fig. 42 Continued

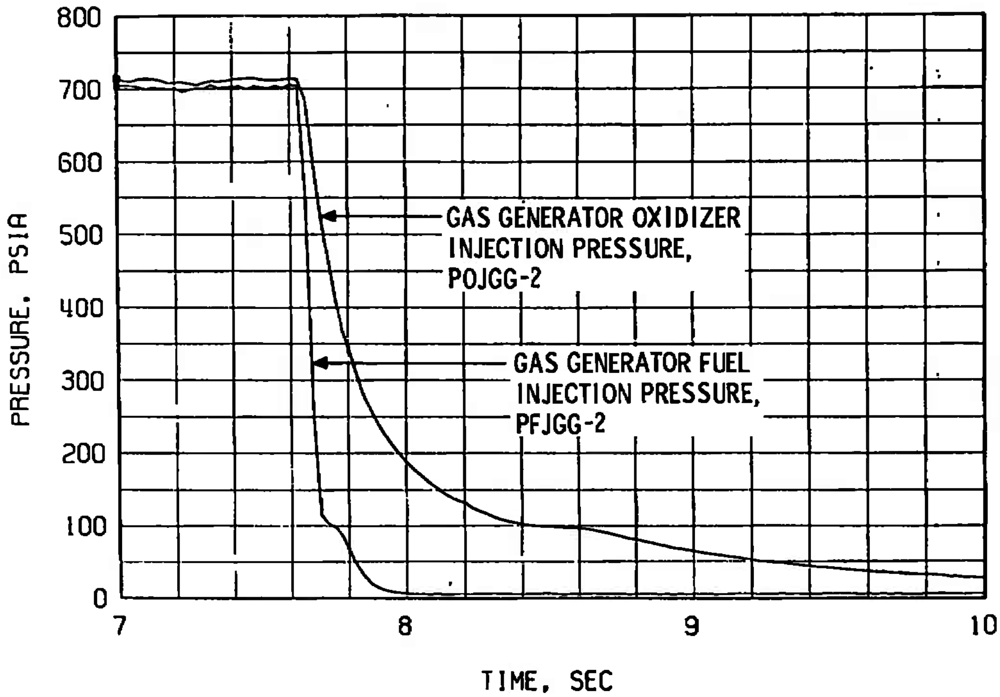


e. Shutdown Transient, Thrust Chamber Fuel System

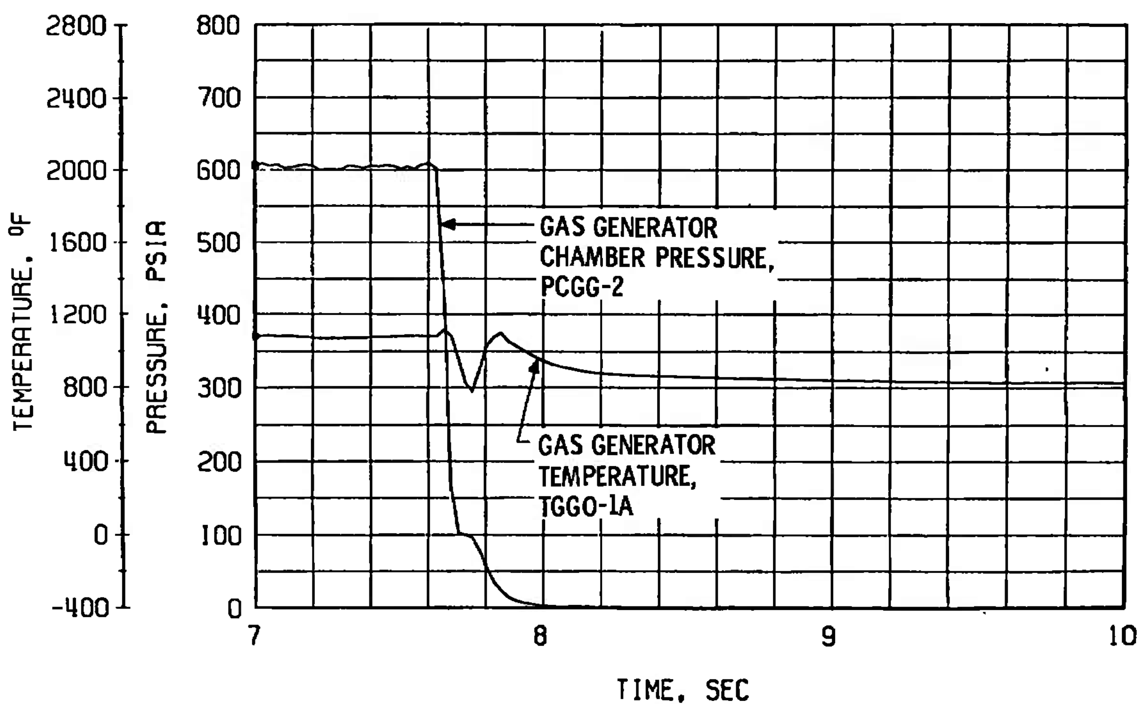


f. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 42 Continued



g. Shutdown Transient, Gas Generator Injection Pressure



h. Shutdown Transient, Gas Generator Temperature and Chamber Pressures

Fig. 42 Concluded

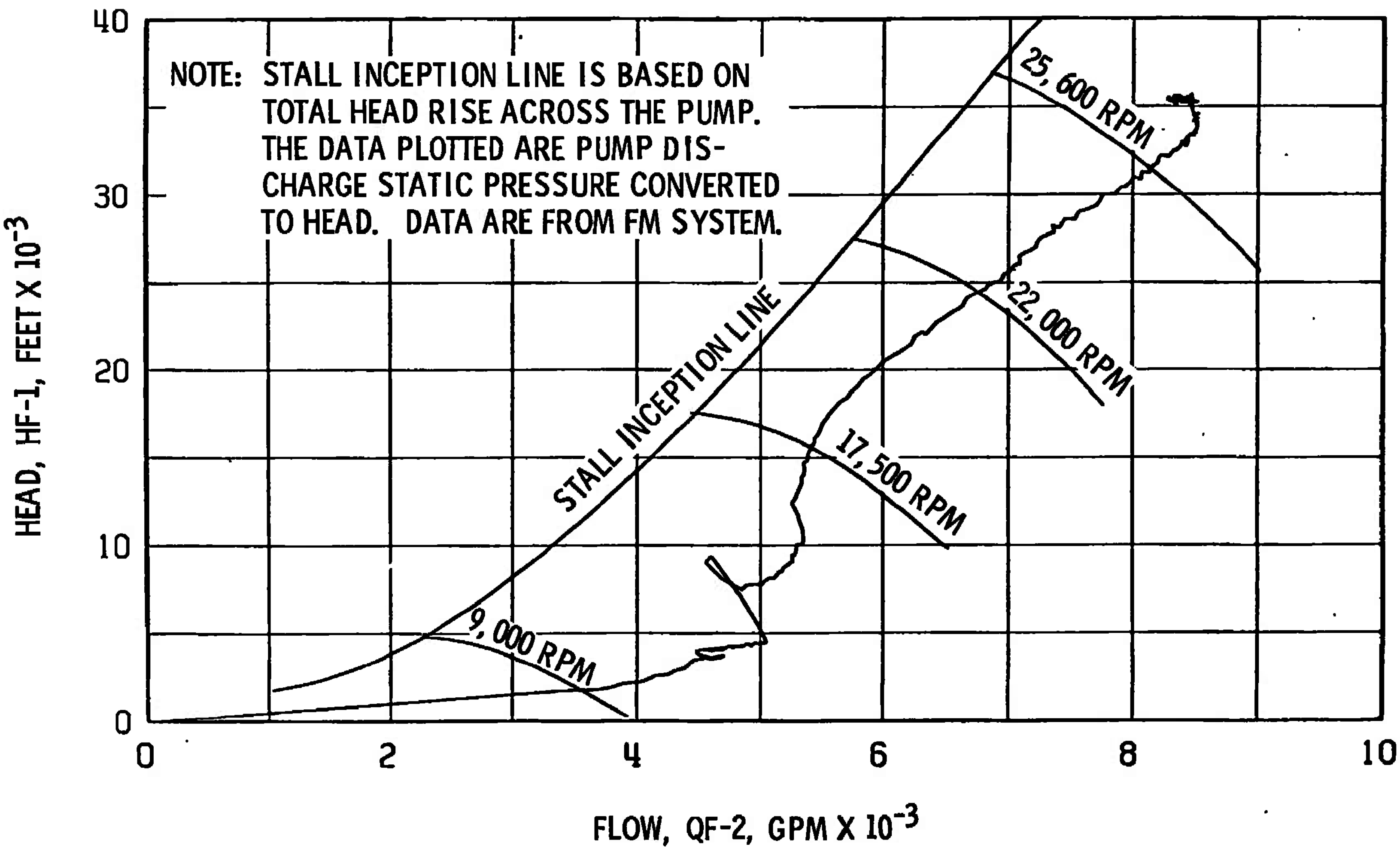
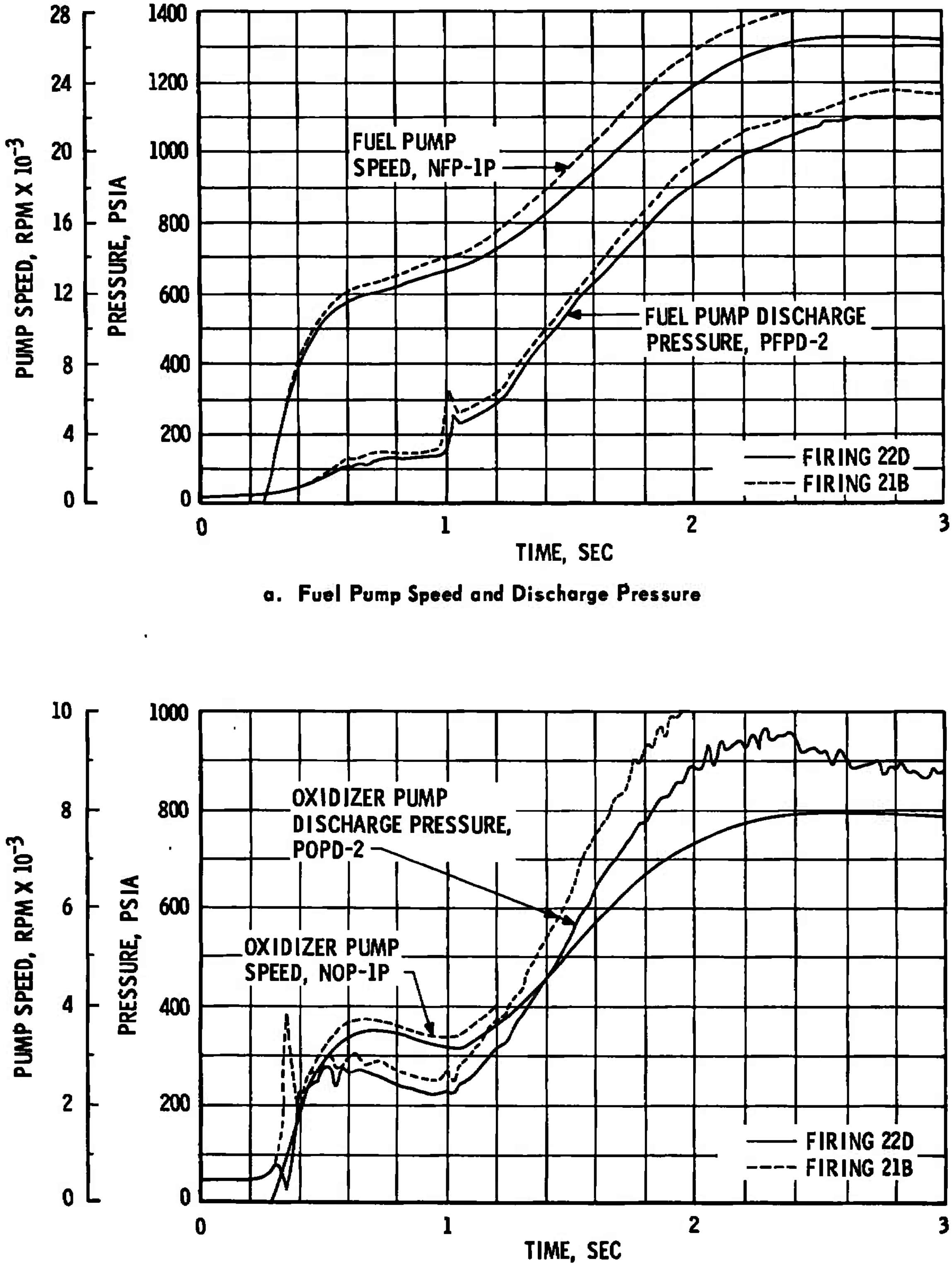


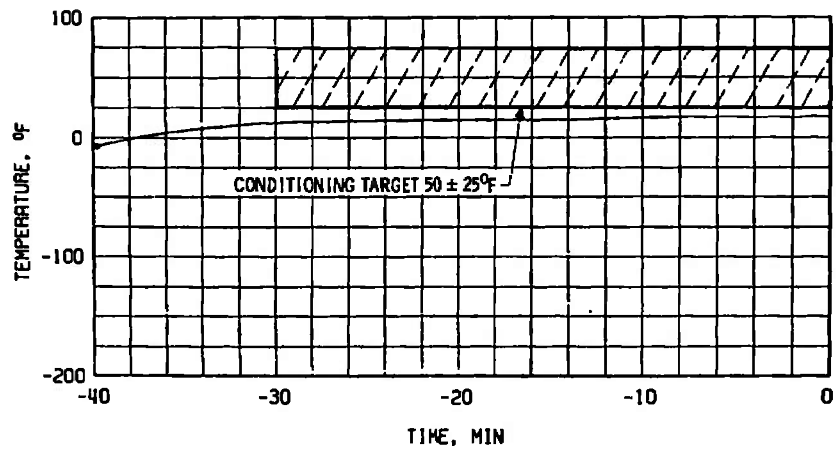
Fig. 43 Fuel Pump Transient Performance, Firing 22D



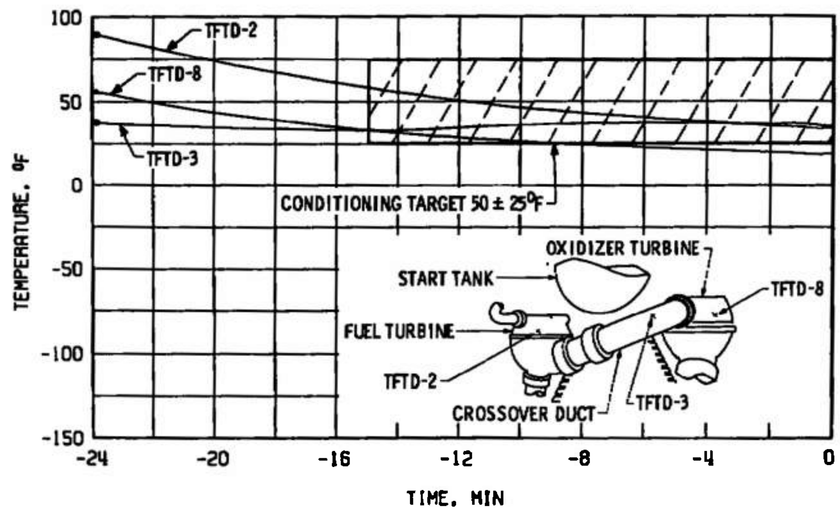
a. Fuel Pump Speed and Discharge Pressure

b. Oxidizer Pump Speed and Discharge Pressure

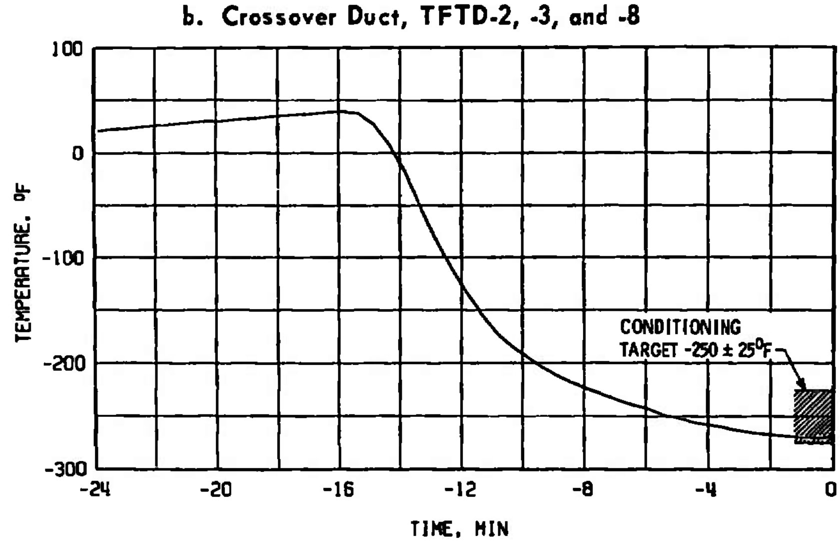
Fig. 44 Comparison of Firings 22D and 21B Start Transient Parameters



a. Start Tank Discharge Valve Opening Control Line, TSTDVOC



b. Crossover Duct, TFTD-2, -3, and -8



c. Thrust Chamber Temperature, TTC-1P

Fig. 45 History of Firing 22E Pre-Fire Temperature Conditioning

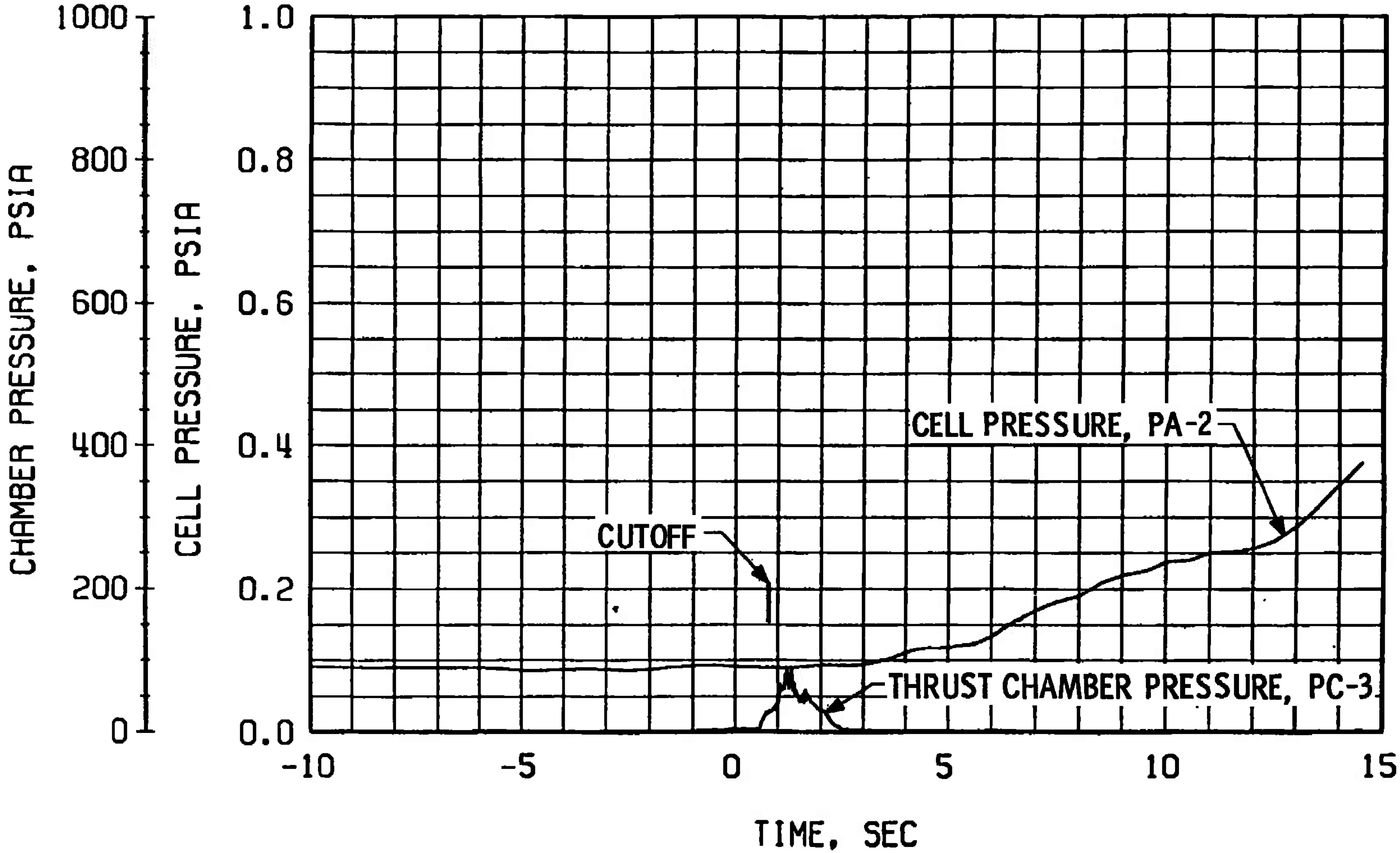
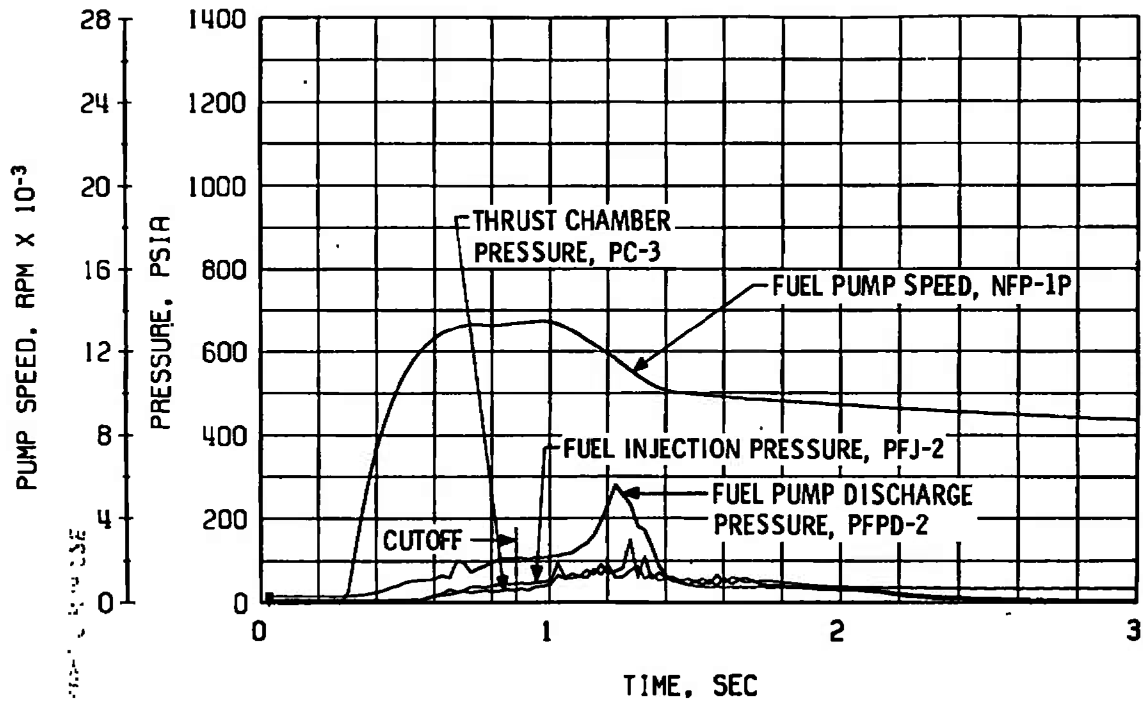
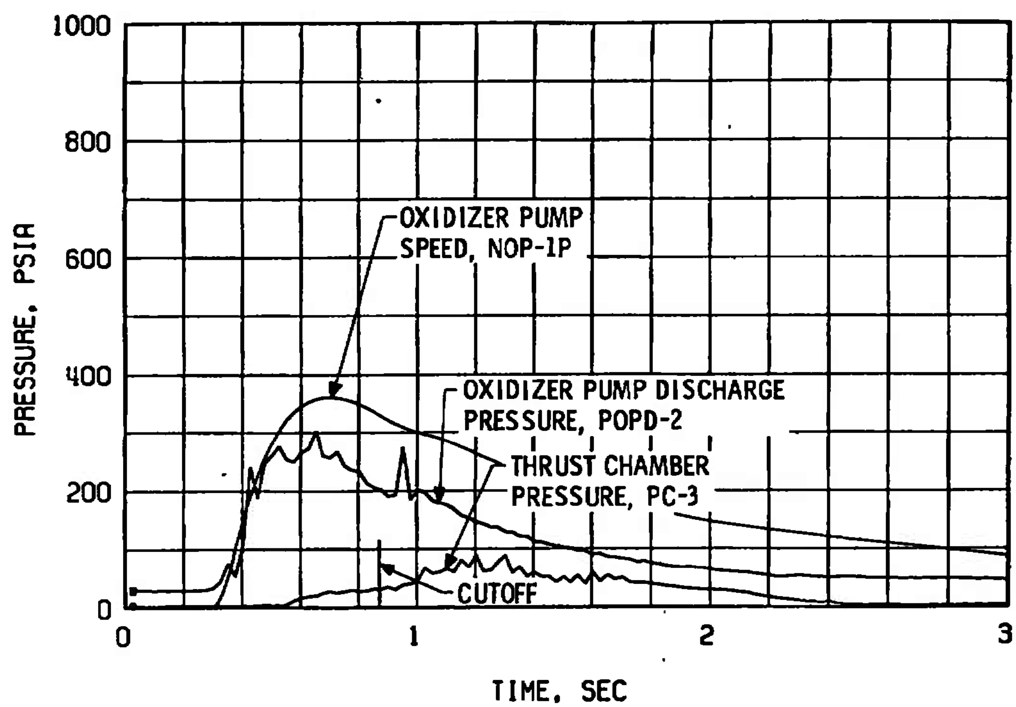


Fig. 46 Engine Chamber and Test Cell Pressure, Firing 22E

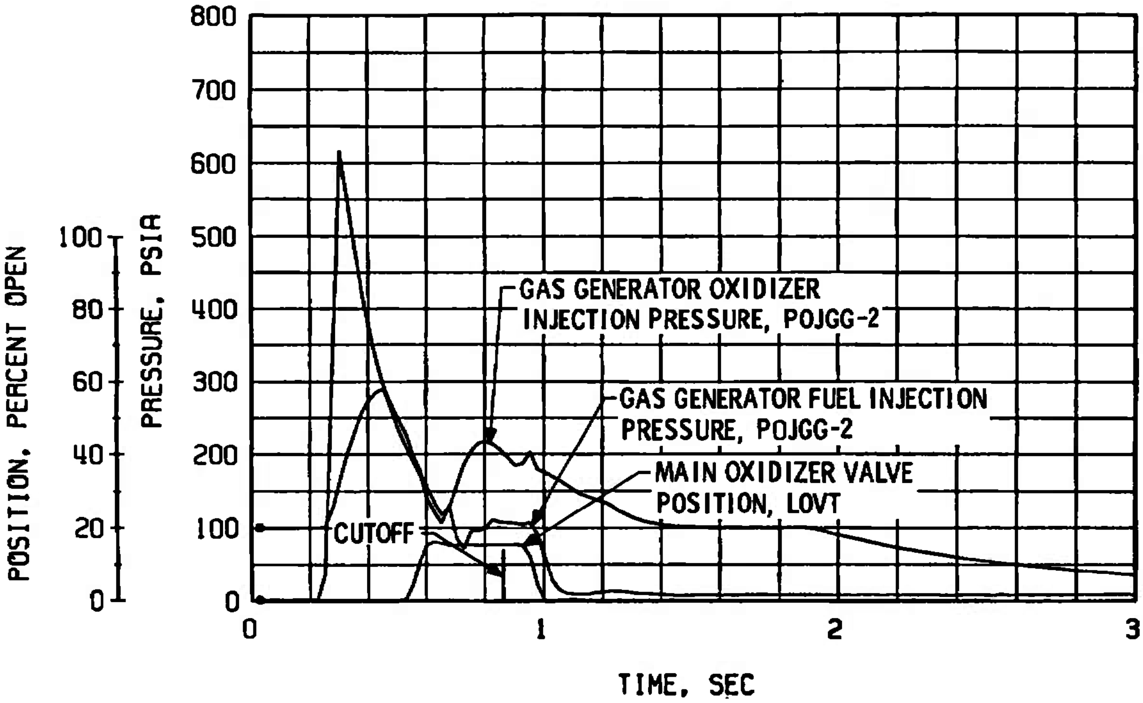


a. Thrust Chamber Fuel System

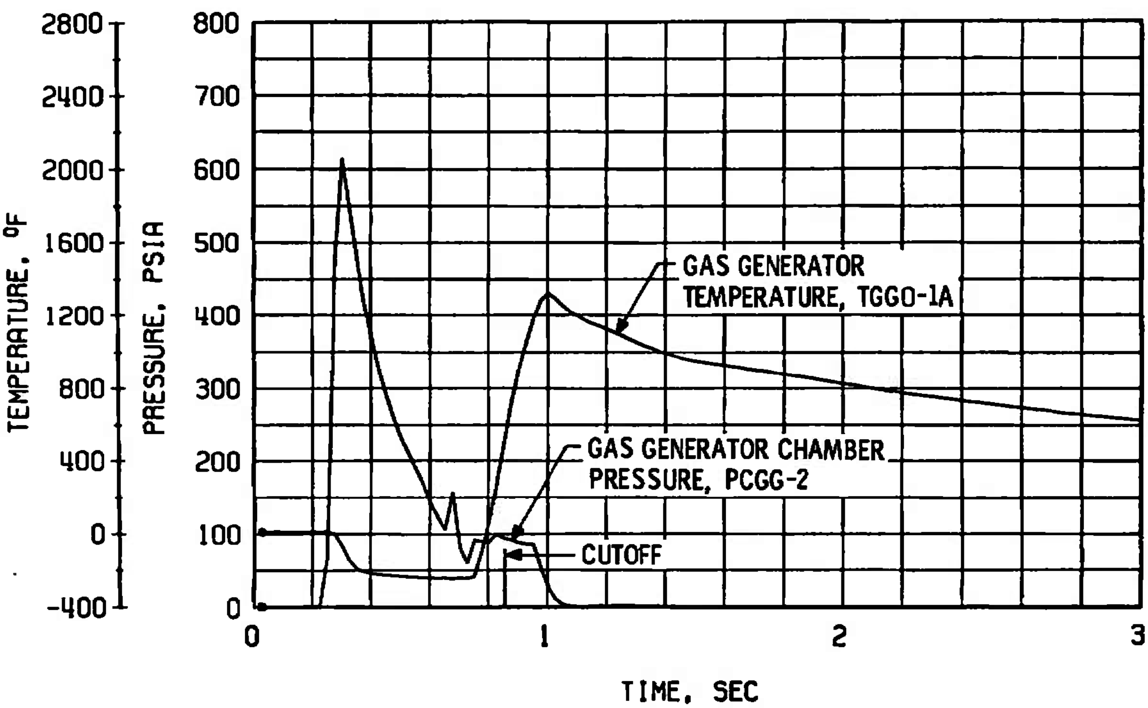


b. Thrust Chamber Oxidizer System

Fig. 47 Engine Start and Shutdown Transients, Firing 22E



c. Gas Generator Fuel Injection Pressures and Main Oxidizer Valve Position



d. Gas Generator Temperature and Chamber Pressures

Fig. 47 Concluded

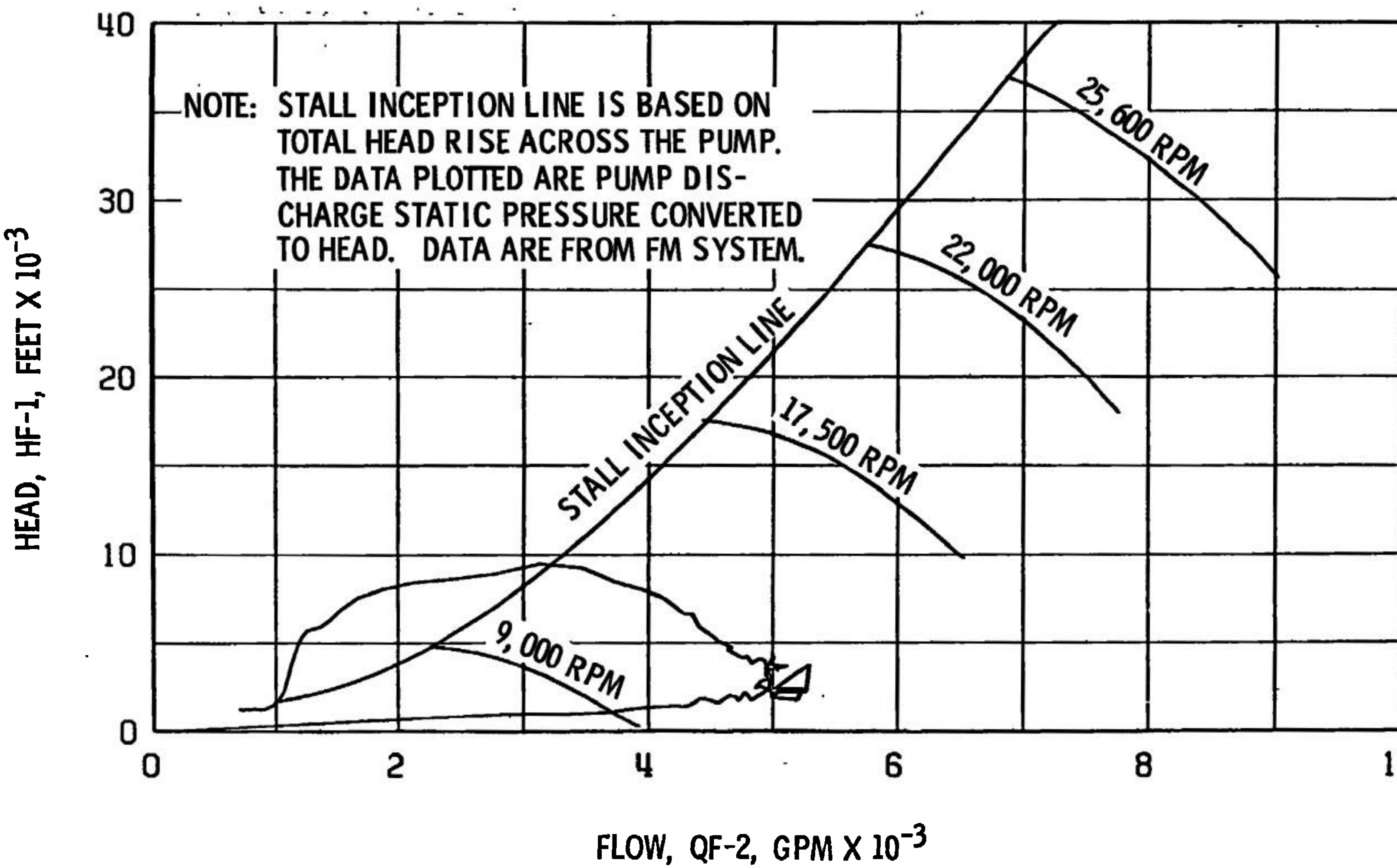


Fig. 48 Fuel Pump Start Transient Performance, Firing 22E

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	460160-31	4072328
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	4088543
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4091740
Helium Regulator Assembly	556948	4072709
Electrical Control Package	502670-11	4078604
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve	409930	4093026
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve	555767	8284307
Ignition Phase Control Valve	555767	8284305
Helium Control Valve	NA5-27273	340919
Start Tank Vent and Relief Valve	557818	4062234
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure-Activated Purge Control Valve	557823	4075865
Pressure-Activated Shutdown Valve Assembly	557817	4067200
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	329

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.500 0.489	December 21, 1967 January 4, 1968	Changes made to obtain desired performance level.
Gas Generator Oxidizer Supply Line	RD251-4106	0.284 0.276	December 21, 1967 January 4, 1968	Changes made to obtain desired performance level.
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430	November 29, 1967	Change made to obtain desired performance level.
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.00	January 18, 1966	Installed before engine delivery to AEDC.
Main Oxidizer Valve Closing Control Line	410437	7.52 scfm	December 21, 1967	Changed to obtain desired valve opening time.
Augmented Spark Igniter Oxidizer Supply Line	406361	0.125	December 21, 1967	Changed to update engine configuration.

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-20 AND J4-1801-22)

Modification	Completion Date	Description of Modification
RFD-AEDC 83-67*	December 17, 1967	Install stud drive, thick-wheel fuel turbopump assembly P/N 460160-31-S/N 4072328
RFD-AEDC 84-67	December 17, 1967	Re-orifice to obtain 230,000 lb thrust level. GG fuel orifice 0.500 in. GG oxidizer orifice 0.284 in.
RFD-AEDC 85-67	December 18, 1967	Install thermostatic-orificed MOV P/N 411031- S/N 4089563 Sequence Ramp Time - $1900 {}^{+20}_{-10}$ msec
RFD-AEDC 86-67	December 15, 1967	Install 0.125 ASI oxidizer Orifice
Test J4-1801-21 December 21, 1967		
RFD-AEDC 87-67	December 28, 1967	Re-orifice to obtain 230,000 lb thrust level. GG fuel orifice 0.489 in. GG oxidizer orifice 0.276 in.
Test J4-1801-22 January 4, 1968		

*RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-20 AND J4-1801-22)

Replacement	Completion Date	Component Replacement
Test J4-1801-21	December 21, 1967	
UCR 007346*	December 30, 1967	Fuel pump turbine shaft seal NA5-26628 P117
UCR 007346	December 30, 1967	Fuel pump intermediate shaft seal NA5-260115 SO72
UCR 007349	December 30, 1967	Fuel pump primary seal drain check valve P/N 557751 S/N 3811483
Test J4-1801-22	January 4, 1968	

*UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

		Time, min: t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10
Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 8 scfm at Customer Connect	10 min; Propellant Drop; 2-min Minimum Following Recirculation; 1 to 3 min
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm	15 min; 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port COA3)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min; On at Engine Cutoff; 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm	15 min; Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to; 15 min
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	On at Engine Cutoff; 10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min	15 min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 48 psia -424 to -416°F	
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	46 min
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	①
Main Oxidizer Valve Actuator Temperature Conditioning	Helium; -300°F to Ambient	②
Start Tank Discharge Valve (Conditioning)	Helium; +40°F to +80°F	②

① Component conditioning to be maintained within limits for last 15 min before engine start.
② Component conditioning to be maintained within limits for last 30 min before engine start.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-	21A Target	21A Actual	21B Target	21B Actual	21C Target	21C Actual	21D Target	21D Actual
Time of Day, hr/Firing Date	1515 /	12-21-67	1757 /	12-21-67	2013 /	12-21-67	2138 /	12-21-67
Pressure Altitude at Engine Start, ft	---	95,000	---	112,000	---	107,000	---	106,000
Firing Duration, sec (1)	32.5	32.575	7.5	7.588	7.5	7.588	7.5	7.588
Fuel Pump Inlet Conditions at Engine Start: Pressure, psia	41.0 ± 1	40.1	27.0 +1 -0	27.0	26.5 +1 -0	26.9	28.5 +1 -0	28.5
Fuel Pump Inlet Conditions at Engine Start: Temperature, °F	-421.4 ± 0.4	-421.6	-420.9 ± 0.4	-420.5	-421.1 ± 0.4	-420.7	-420.1 ± 0.4	-420.1
Oxidizer Pump Inlet Conditions at Engine Start: Pressure, psia	45.0 ± 1	45.2	45.0 ± 1	45.3	45.0 ± 1	44.9	45.0 ± 1	45.2
Oxidizer Pump Inlet Conditions at Engine Start: Temperature, °F	-294.5 ± 0.4	-294.6	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.6	-294.5 ± 0.4	-294.6
Start Tank Conditions at Engine Start: Pressure, psia	1300 ± 10	1301	1300 ± 10	1308	1400 ± 10	1405	1400 ± 10	1400
Start Tank Conditions at Engine Start: Temperature, °F	-300 ± 10	-294	-300 ± 10	-306	-240 ± 10	-243	-240 ± 10	-242
Helium Tank Conditions at Engine Start: Pressure, psia	---	2185	---	2037	---	2155	---	2043
Helium Tank Conditions at Engine Start: Temperature, °F	---	-285	---	-105	---	-240	---	-242
Thrust Chamber Temperature Conditions at Engine Start, °F: Throat	-150 +20 -10	-128	-150 +20 -10	-142	-150 +20 -10	-132	-275 +0 -25	-275
Thrust Chamber Temperature Conditions at Engine Start, °F: Average	---	-175	---	-185	---	-173	---	-300
Crossover Duct Temperature at Engine Start, °F (2): TFTD-2	50 ± 25	58	50 ± 25	43	50 ± 25	42	50 ± 25	47
Crossover Duct Temperature at Engine Start, °F (2): TFTD-3	50 ± 25	76	50 ± 25	41	50 ± 25	64	50 ± 25	66
Crossover Duct Temperature at Engine Start, °F (2): TFTD-8	50 ± 25	55	50 ± 25	46	50 ± 25	50	50 ± 25	48
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F	---	+16	---	-8	---	+8	---	-6
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F	-100 ± 25	-80	-100 ± 25	-126	-100 ± 25	-115	-100 ± 25	-110
Fuel Lead Time, sec (1)	1.00 ± 0.05	1.000	1.00 ± 0.05	1.100	1.00 ± 0.05	1.005	1.00 ± 0.05	1.010
Propellant in Engine Time, min	---	78	---	115	---	113	---	38
Propellant Recirculation Time, min	10	11	10	11	10	10	10	11.5
Prevalve Sequencing Logic	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Bootstrap Line Temperature at Engine Start, °F: TOBS-2B	---	18	---	1	---	11	---	10
Bootstrap Line Temperature at Engine Start, °F: TOBS-3	---	-2	---	-2	---	-8	---	-9
Bootstrap Line Temperature at Engine Start, °F: TOBS-4	---	-41	---	-49	---	-43	---	-44
Start Tank Discharge Valve Body Temperature at Engine Start, °F (2)	50 ± 25	51	50 ± 25	37	50 ± 25	41	50 ± 25	38
Gas Generator Control Valve Body Temperature at Engine Start, °F	---	47	---	6	---	3	---	4
Vibration Safety Counts Duration (msec) and Occurrence Time (sec) from t_0 (1)	--- / ---	6 / 0.950	--- / ---	50 / 0.970	--- / ---	26 / 0.975	--- / ---	123 / 0.975
Gas Generator Outlet Temperature, °F: Initial Peak	---	1610	---	1140	---	1795	---	1860
Gas Generator Outlet Temperature, °F: Overshoot	---	1885	---	1140	---	2125	---	1665
Main Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)	---	0.950	---	0.970	---	0.975	---	0.985
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)	---	1.800	---	1.180	---	1.145 / 1.305 (4)	---	1.030
Main-Stage Pressure No. 2, sec (Ref. t_0) (1)	---	1.570	---	1.645	---	1.595	---	1.665
550-psia Chamber Pressure Attained, sec (Ref. t_0)	---	1.875	---	1.883	---	1.858	---	1.858
Propellant Utilization Valve Position at Engine Start, deg — Engine Start/t_0 + 10 sec	0 / -33	0 / -33	0 / ---	0 / ---	0 / ---	0 / ---	0 / ---	0 / ---

Firing Number, J4-1801-	22A Target	22A Actual	22B Target	22B Actual	22C Target	22C Actual	22D Target	22D Actual	22E Target	22E Actual
Time of Day, hr/Firing Date	1223 /	1-4-68	1636 /	1-4-68	1537 /	1-4-68	1736 /	1-4-68	1837 /	1-4-68
Pressure Altitude at Engine Start, ft	---	101,000	---	109,000	---	109,000	---	112,000	---	112,000
Firing Duration, sec (1)	32.5	32.576	7.1	7.586	7.5	7.588	7.5	7.589	0.8	0.871
Fuel Pump Inlet Conditions at Engine Start: Pressure, psia	25.5 +1 -0	25.6	41.0 ± 1	41.0	25.5 +1 -0	26.8	25.5 +1 -0	26.2	21.5 +1 -0	22.3
Fuel Pump Inlet Conditions at Engine Start: Temperature, °F	-421.4 ± 0.4	-421.1	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-420.7	-421.4 ± 0.4	-421.4	-421.1 ± 0.4	-421.2
Oxidizer Pump Inlet Conditions at Engine Start: Pressure, psia	45.0 ± 1	45.3	45.0 ± 1	45.1	45.0 ± 1	44.8	45.0	44.4	28.0 ± 1	28.1
Oxidizer Pump Inlet Conditions at Engine Start: Temperature, °F	-294.5 ± 0.4	-295.0	-294.5 ± 0.4	-294.2	-294.5 ± 0.4	-294.9	-294.5 ± 0.4	-294.5	-295.0 ± 0.4	-294.7
Start Tank Conditions at Engine Start: Pressure, psia	1380 ± 10	1388	1380 ± 10	1380	1300 ± 10	1304	1200 ± 10	1203	1400 ± 10	1409
Start Tank Conditions at Engine Start: Temperature, °F	-270 ± 10	-272	-270 ± 10	-270	-300 ± 10	-298	-300 ± 10	-299	-240 ± 10	-241
Helium Tank Conditions at Engine Start: Pressure, psia	---	1190	---	2285	---	2230	---	2235	---	2670
Helium Tank Conditions at Engine Start: Temperature, °F	---	-267	---	-267	---	-291	---	-296	---	-238
Thrust Chamber Temperature Conditions at Engine Start, °F: Throat	-250 ± 25	-266	-250 ± 25	-258	-250 ± 25	-257	-150 +20 -10	-151	-250 ± 25	-261
Thrust Chamber Temperature Conditions at Engine Start, °F: Average	---	-301	---	-295	---	-299	---	-204	---	-291
Crossover Duct Temperature at Engine Start, °F (2): TFTD-2	50 ± 25	26	50 ± 25	26	50 ± 25	19	50 ± 25	34	50 ± 25	34
Crossover Duct Temperature at Engine Start, °F (2): TFTD-3	50 ± 25	39	50 ± 25	37	50 ± 25	48	50 ± 25	39	50 ± 25	36
Crossover Duct Temperature at Engine Start, °F (2): TFTD-8	50 ± 25	35	50 ± 25	19	50 ± 25	20	50 ± 25	19	50 ± 25	19
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F	---	-14	---	-30	---	-20	---	-20	---	-30
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F	-100 ± 50	-122	-100 ± 50	-134	-100 ± 50	-104	-100 ± 50	-139	---	-131
Fuel Lead Time, sec (1)	1.0 ± 0.05	1.001	1.0 ± 0.05	1.000	1.0 ± 0.05	1.000	1.0 ± 0.05	1.002	1.0 ± 0.05	1.002
Propellant in Engine Time, min	---	95	---	30	---	69	---	30	---	31
Propellant Recirculation Time, min	10	34.5	10	10	10	10	10	11	10	10
Prevalve Sequencing Logic	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Bootstrap Line Temperature at Engine Start, °F: TOBS-2B	---	-6	---	-17	---	5	---	11	---	24
Bootstrap Line Temperature at Engine Start, °F: TOBS-3	---	-26	---	-35	---	-12	---	-7	---	6
Bootstrap Line Temperature at Engine Start, °F: TOBS-4	---	-64	---	-67	---	-44	---	-30	---	-24
Start Tank Discharge Valve Body Temperature at Engine Start, °F (2)	50 ± 25	28	50 ± 25	21	50 ± 25	25	50 ± 25	17	50 ± 20	17
Gas Generator Control Valve Body Temperature at Engine Start, °F	---	10	---	-18	---	14	---	-18	---	-18
Vibration Safety Counts Duration (msec) and Occurrence Time (sec) from t_0 (1)	--- / ---	40 / 0.980	--- / ---	200 / 0.965	--- / ---	150 / 0.985	--- / ---	11 / 0.990	--- / ---	0 / ---
Gas Generator Outlet Temperature, °F: Initial Peak	---	1740	---	1770	---	1690	---	1770	---	1300 at t_0 + 1.0 sec
Gas Generator Outlet Temperature, °F: Overshoot	---	1500	---	---	---	---	---	1560	---	---
Main Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)	---	0.985	---	0.965	---	0.985	---	0.990	---	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)	---	1.033 / 1.155 (4)	---	1.030	---	1.025	---	1.165	---	---
Main-Stage Pressure No. 2, sec (Ref. t_0) (1)	---	1.690	---	1.640	---	1.735	---	1.650	---	---
550-psia Chamber Pressure Attained, sec (Ref. t_0)	---	1.975	---	1.950	---	2.008	---	1.892	---	---
Propellant Utilization Valve Position at Engine Start, deg — Engine Start/t_0 + 10 sec	0 / -33	0 / -33	0 / ---	0 / ---	0 / ---	0 / ---	0 / ---	0 / ---	0 / ---	0 / ---

Notes: (1) Data Reduced from Oscillogram.
(2) Component Conditioning to be Maintained within Limits for Last 15 min before Engine Start.
(3) Component Conditioning to be Maintained within Limits for Last 30 min before Engine Start.
(4) Only 1 deg of Movement between these Times.

TABLE VII
ENGINE VALVE TIMINGS

Start

Firing Number J4-1801-	Start Tank Discharge Valve: Time of Opening Signal	Start Tank Discharge Valve: Valve Delay Time, sec	Start Tank Discharge Valve: Valve Opening Time, sec	Start Tank Discharge Valve: Time of Closing Signal	Start Tank Discharge Valve: Valve Delay Time, sec	Start Tank Discharge Valve: Valve Closing Time, sec	Main Fuel Valve: Time of Opening Signal	Main Fuel Valve: Valve Delay Time, sec	Main Fuel Valve: Valve Opening Time, sec	Main Oxidizer Valve, First Stage: Time of Opening Signal	Main Oxidizer Valve, First Stage: Valve Delay Time, sec	Main Oxidizer Valve, First Stage: Valve Opening Time, sec
21A	0	0.140	0.125	0.450	0.080	1.235	-1.000	0.050	0.060	0.450	0.065	0.050
21B	0	0.140	0.130	0.450	0.090	1.235	-1.000	0.055	0.075	0.450	0.065	0.055
21C	0	0.140	0.135	0.460	0.085	1.240	-1.005	0.060	0.065	0.450	0.065	0.060
21D	0	0.145	0.130	0.450	0.085	1.235	-1.010	0.055	0.070	0.450	0.055	0.055
Pre-Fire Final Sequence	0	0.088	0.110	0.450	0.085	1.255	-1.030	0.045	0.070	0.450	0.050	0.050
22A	0	0.145	0.135	0.445	0.090	1.230	-1.001	0.060	0.080	0.445	0.060	0.050
22B	0	0.145	0.135	0.445	0.090	1.240	-1.000	0.060	0.060	0.445	0.055	0.055
22C	0	0.140	0.130	0.445	0.095	1.245	-1.000	0.060	0.060	0.445	0.060	0.055
22D	0	0.140	0.125	0.445	0.085	1.240	-1.002	0.060	0.080	0.445	0.055	0.055
22E	0	0.145	0.135	0.445	0.080	1.240	-1.002	0.060	0.065	0.445	0.055	0.065
Pre-Fire Final Sequence	0	0.100	0.115	0.445	0.095	1.245	-1.000	0.045	0.070	0.445	0.050	0.055

Start (continued)

Firing Number J4-1801-	Main Oxidizer Valve, Second Stage: Time of Opening Signal	Main Oxidizer Valve, Second Stage: Valve Delay Time, sec	Main Oxidizer Valve, Second Stage: Valve Opening Time, sec	Gas Generator Fuel Poppet: Time of Opening Signal	Gas Generator Fuel Poppet: Valve Delay Time, sec	Gas Generator Fuel Poppet: Valve Opening Time, sec	Gas Generator Oxidizer Poppet: Time of Opening Signal	Gas Generator Oxidizer Poppet: Valve Delay Time, sec	Gas Generator Oxidizer Poppet: Valve Opening Time, sec	Oxidizer Turbine Bypass Valve: Time of Closing Signal	Oxidizer Turbine Bypass Valve: Valve Delay Time, sec	Oxidizer Turbine Bypass Valve: Valve Closing Time, sec
21A	0.450	0.740	2.140	0.450	0.115	0.025	0.450	0.185	0.070	0.450	0.235	0.270
21B	0.450	0.750	2.120	0.450	0.115	0.030	0.450	0.190	0.075	0.450	0.235	0.265
21C	0.450	0.705	2.180	0.450	0.115	0.025	0.450	0.190	0.075	0.450	0.220	0.275
21D	0.450	0.585	2.240	0.450	0.115	0.030	0.450	0.190	0.070	0.450	0.230	0.285
Pre-Fire Final Sequence	0.450	0.640	1.930	0.450	0.087	0.030	0.450	0.145	0.065	0.450	0.220	0.280
22A	0.445	0.680	2.090	0.445	0.115	0.030	0.445	0.190	0.065	0.145	0.240	0.265
22B	0.445	0.595	2.165	0.445	0.115	0.030	0.445	0.195	0.090	0.145	0.240	0.270
22C	0.445	0.585	2.160	0.445	0.115	0.040	0.445	0.195	0.070	0.145	0.240	0.275
22D	0.445	0.715	2.020	0.445	0.115	0.030	0.445	0.195	0.080	0.145	0.230	0.270
22E	---	---	---	0.445	0.115	0.030	0.445	0.195	0.075	0.145	0.225	0.230
Pre-Fire Final Sequence	0.445	0.620	1.925	0.445	0.080	0.030	0.445	0.130	0.065	0.145	0.225	0.270

Shutdown

Firing Number J4-1801-	Main Fuel Valve: Time of Closing Signal	Main Fuel Valve: Valve Delay Time, sec	Main Fuel Valve: Valve Closing Time, sec	Main Oxidizer Valve: Time of Closing Signal	Main Oxidizer Valve: Valve Delay Time, sec	Main Oxidizer Valve: Valve Closing Time, sec	Gas Generator Fuel Poppet: Time of Closing Signal	Gas Generator Fuel Poppet: Valve Delay Time, sec	Gas Generator Fuel Poppet: Valve Closing Time, sec	Gas Generator Oxidizer Poppet: Time of Closing Signal	Gas Generator Oxidizer Poppet: Valve Delay Time, sec	Gas Generator Oxidizer Poppet: Valve Closing Time, sec	Oxidizer Turbine Bypass Valve: Time of Opening Signal	Oxidizer Turbine Bypass Valve: Valve Delay Time, sec	Oxidizer Turbine Bypass Valve: Valve Opening Time, sec
21A	0	0.135	0.325	0	0.080	0.180	0	0.050	0.025	0	0.020	0.020	0	0.225	0.470
21B	0	0.135	0.360	0	0.090	0.180	0	0.055	0.020	0	0.020	0.025	0	0.220	0.480
21C	0	0.140	0.365	0	0.080	0.175	0	0.060	0.020	0	0.020	0.020	0	0.210	0.445
21D	0	0.135	0.345	0	0.075	0.175	0	0.055	0.020	0	0.015	0.025	0	0.205	0.350
Pre-Fire Final Sequence	0	0.085	0.230	0	0.060	0.135	0	0.080	0.025	0	0.050	0.020	0	0.210	0.535
22A	0	0.130	0.355	0	0.080	0.185	0	0.050	0.020	0	0.025	0.015	0	0.210	0.430
22B	0	0.130	0.365	0	0.075	0.185	0	0.070	0.020	0	0.025	0.020	0	0.205	0.355
22C	0	0.130	0.340	0	0.070	0.180	0	0.055	0.020	0	0.025	0.020	0	0.195	0.300
22D	0	0.130	0.350	0	0.075	0.185	0	0.060	0.020	0	0.030	0.020	0	0.195	0.300
22E	0	0.110	0.305	0	0.030	0.035	0	0.070	0.020	0	0.040	0.020	0	0.050	0.330
Pre-Fire Final Sequence	0	0.090	0.245	0	0.065	0.135	0	0.080	0.025	0	0.050	0.020	0	0.205	0.490

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		21A		22A	
		Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	246,602	244,516	237,647	236,097
	Chamber Pressure, psia	822	812	795	787
	Mixture Ratio	5.373	5.407	5.418	5.411
	Fuel Weight Flow, lb_m/sec	88.75	87.28	85.59	84.78
	Oxidizer Weight Flow, lb_m/sec	476.88	471.93	463.74	458.78
	Total Weight Flow, lb_m/sec	565.64	559.21	549.33	543.56
Thrust Chamber Performance	Mixture Ratio	5.571	5.610	5.618	5.613
	Total Weight Flow, lb_m/sec	558.17	551.80	542.21	536.49
	Characteristic Velocity, ft/sec	8062.8	8050.9	8027.6	8028.3
Fuel Turbopump Performance	Pump Efficiency, percent	73.5	73.5	73.9	73.9
	Pump Speed, rpm	28,237	28,016	27,481	27,320
	Turbine Efficiency, percent	64.1	63.9	63.4	63.3
	Turbine Pressure Ratio	7.25	7.25	7.25	7.25
	Turbine Inlet Temperature, °F	1233	1220	1209	1191
	Turbine Weight Flow, lb_m/sec	7.47	7.41	7.11	7.07
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.4	80.4	80.4	80.4
	Pump Speed, rpm	8899	8843	8664	8611
	Turbine Efficiency, percent	49.8	49.7	49.0	48.9
	Turbine Pressure Ratio	2.65	2.65	2.66	2.66
	Turbine Inlet Temperature, °F	793	784	776	763
	Turbine Weight Flow, lb_m/sec	6.62	6.57	6.30	6.27
Gas Generator Performance	Mixture Ratio	0.959	0.952	0.945	0.934
	Chamber Pressure, psia	727	719	690	683

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC Test J4-1801-21 and 22 is tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
LIST OF ENGINE INSTRUMENTATION

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
	Sparks							
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2					x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF5	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHROP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure							
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		**rpm**					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		**°F**					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				

TABLE III-1 (Continued)

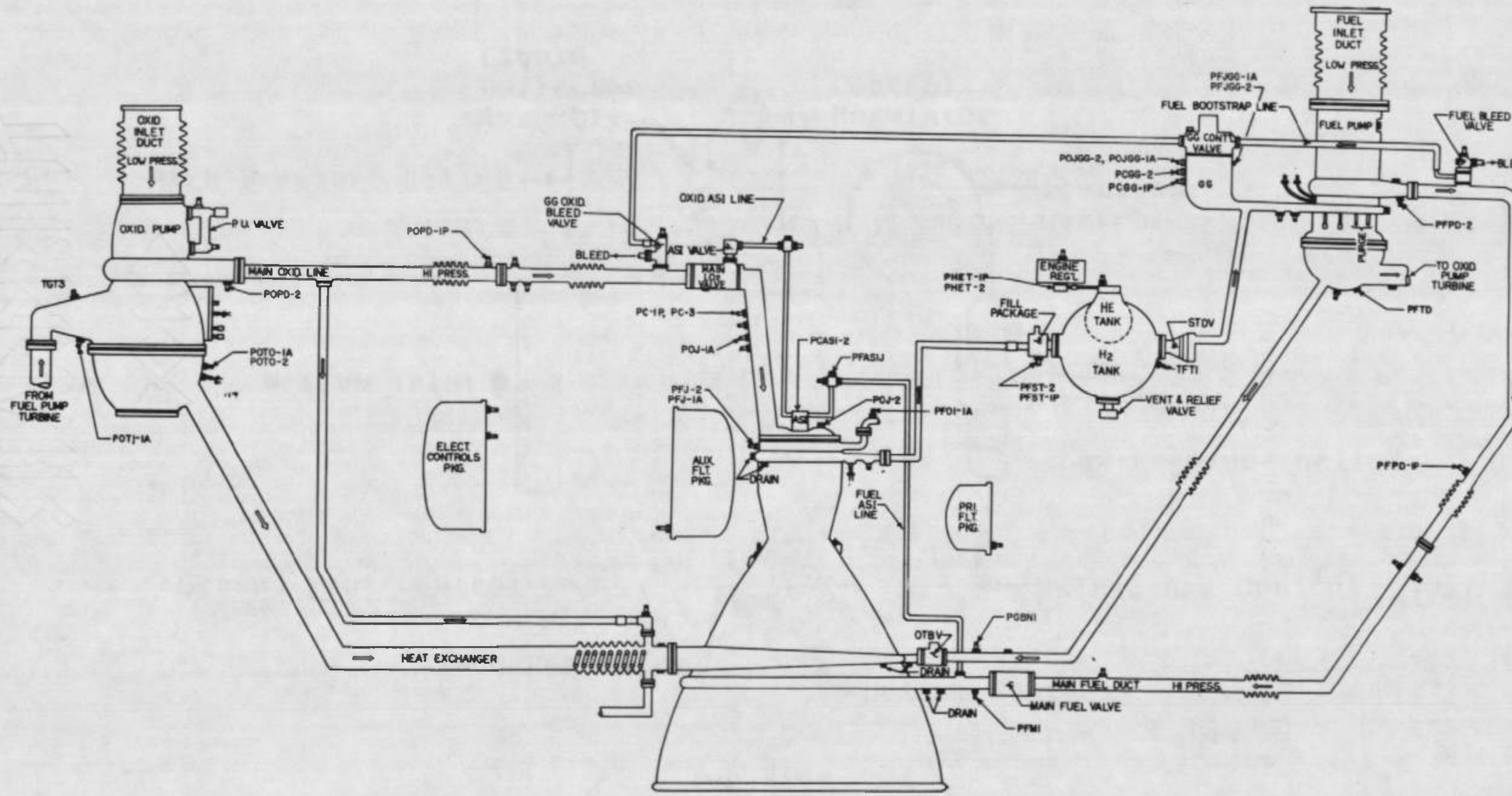
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TECP-1P	Electrical Controls Package	NST1A	-300 to -200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	1FT1	-425 to +100	x		x		
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNTI	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to -250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOT1-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				

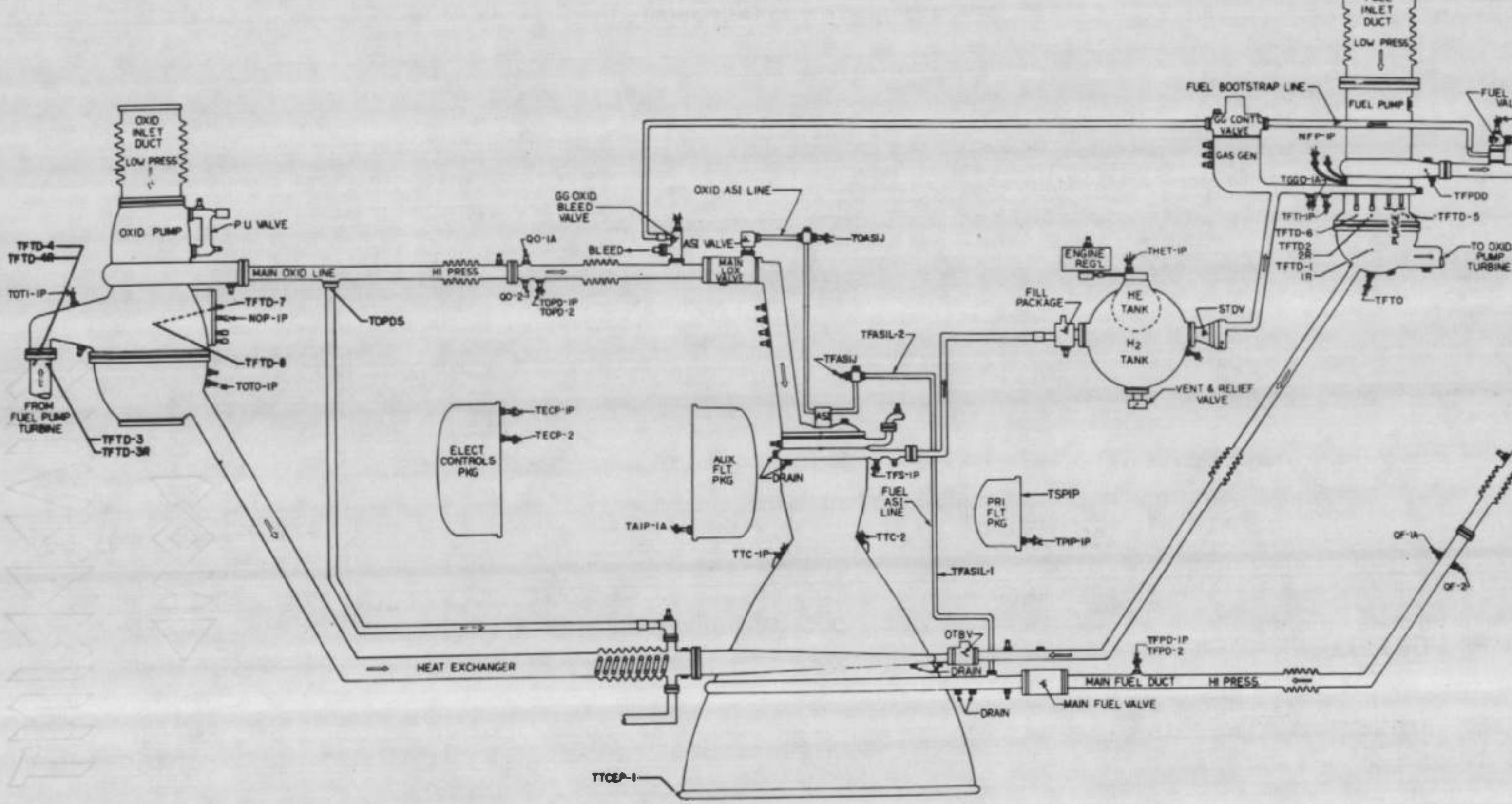
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		**°F**					
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVCC	Start Tank Discharge Valve Closing Control Port		-350 to +100	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1F	Thrust Chamber Jacket (Control)	CS1	-425 to -500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to -500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		**g**					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		**Volts**					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

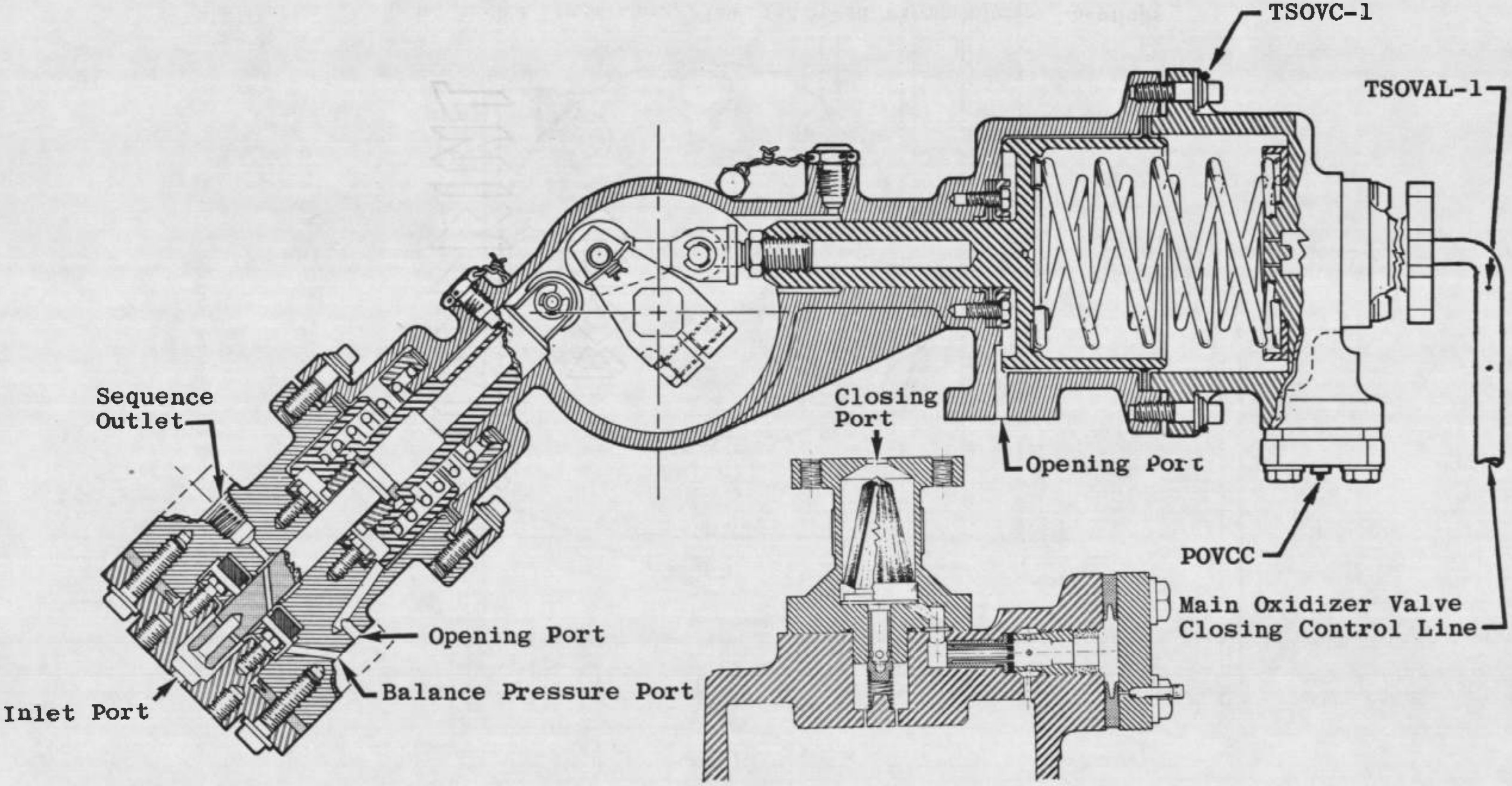


a. Engine Pressure Tap Locations

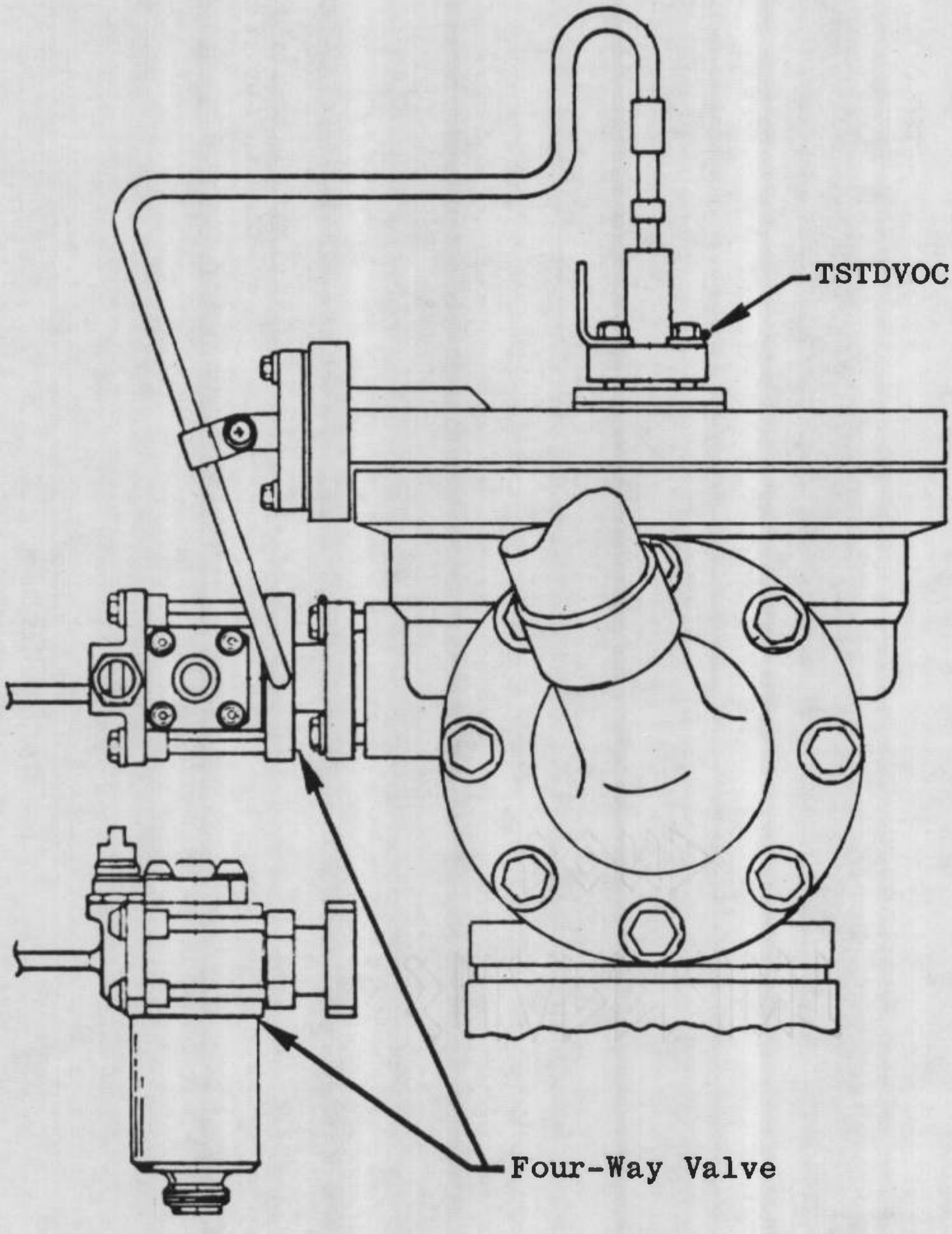
Fig. III-1 Instrumentation Locations



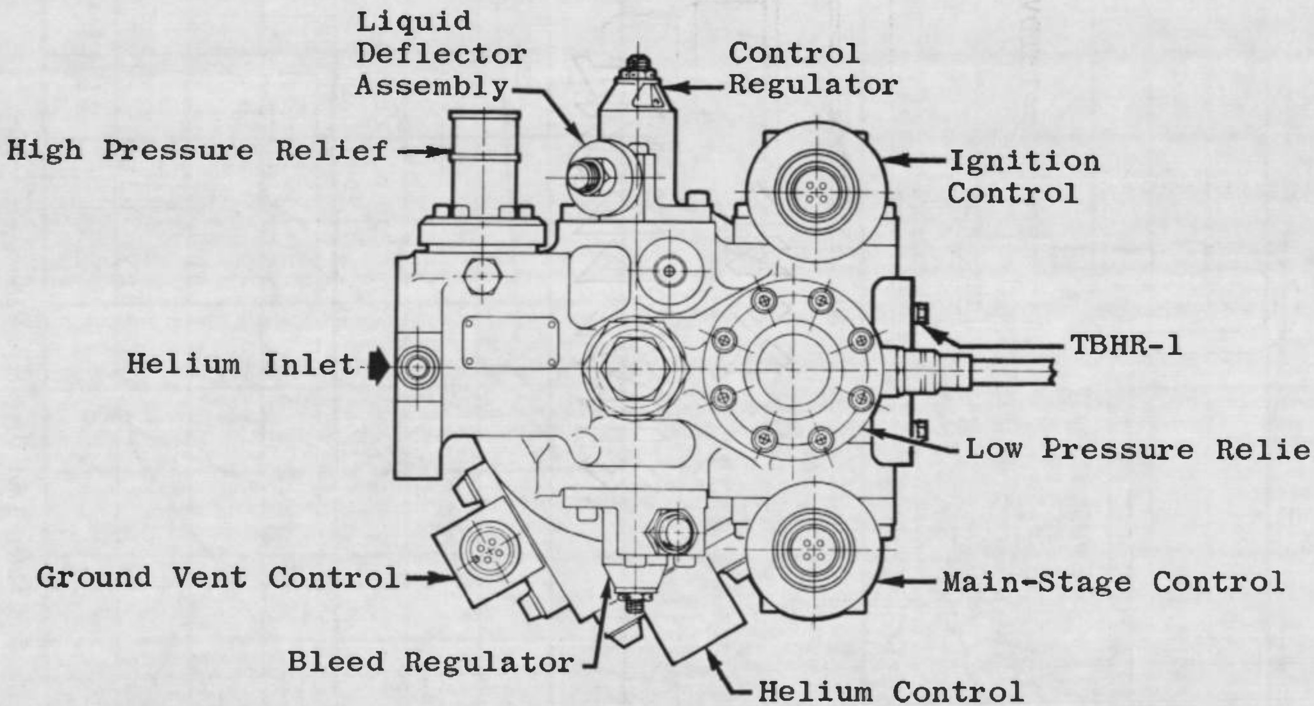
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

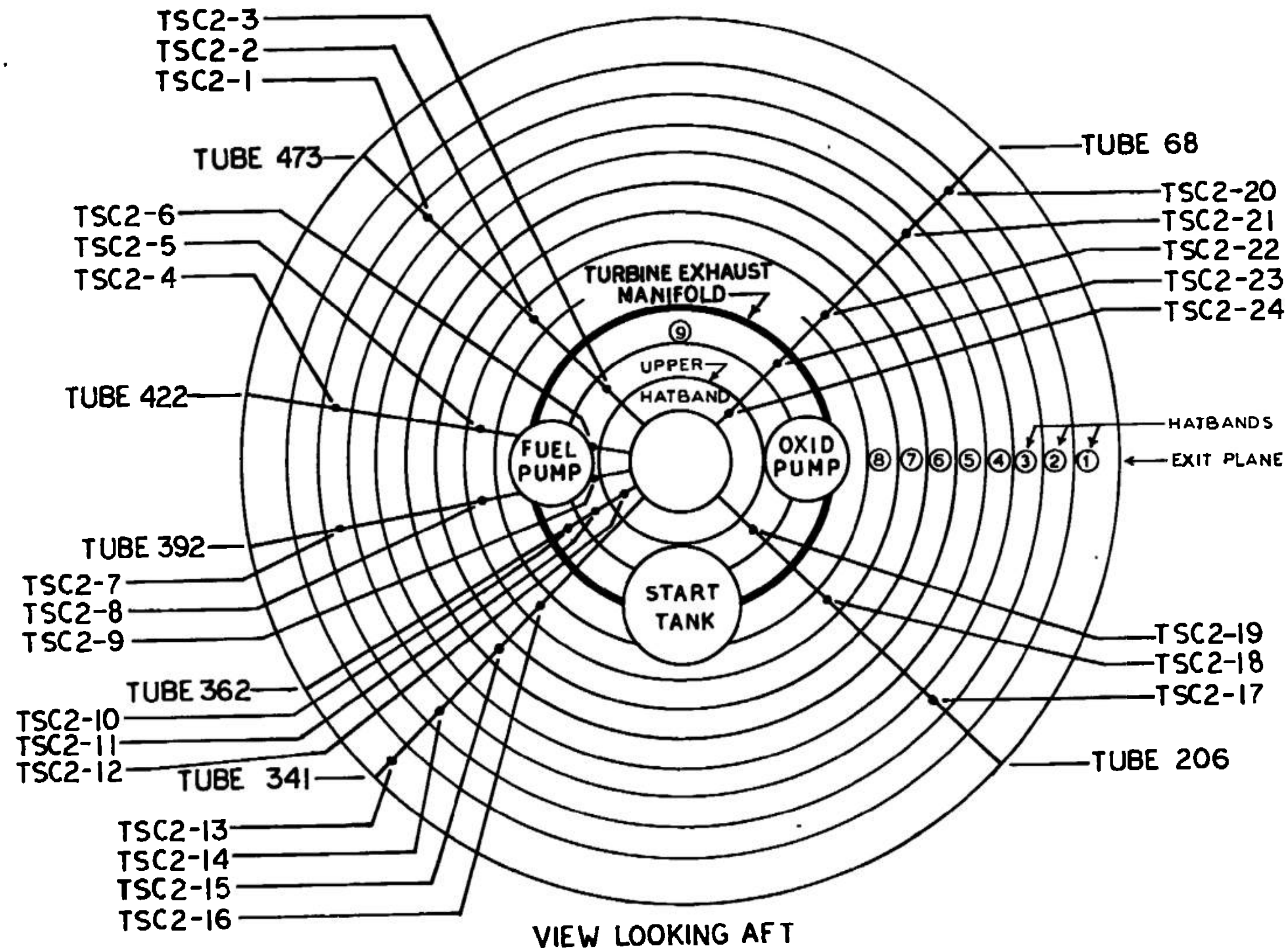


d. Start Tank Discharge Valve
Fig. III-1 Continued

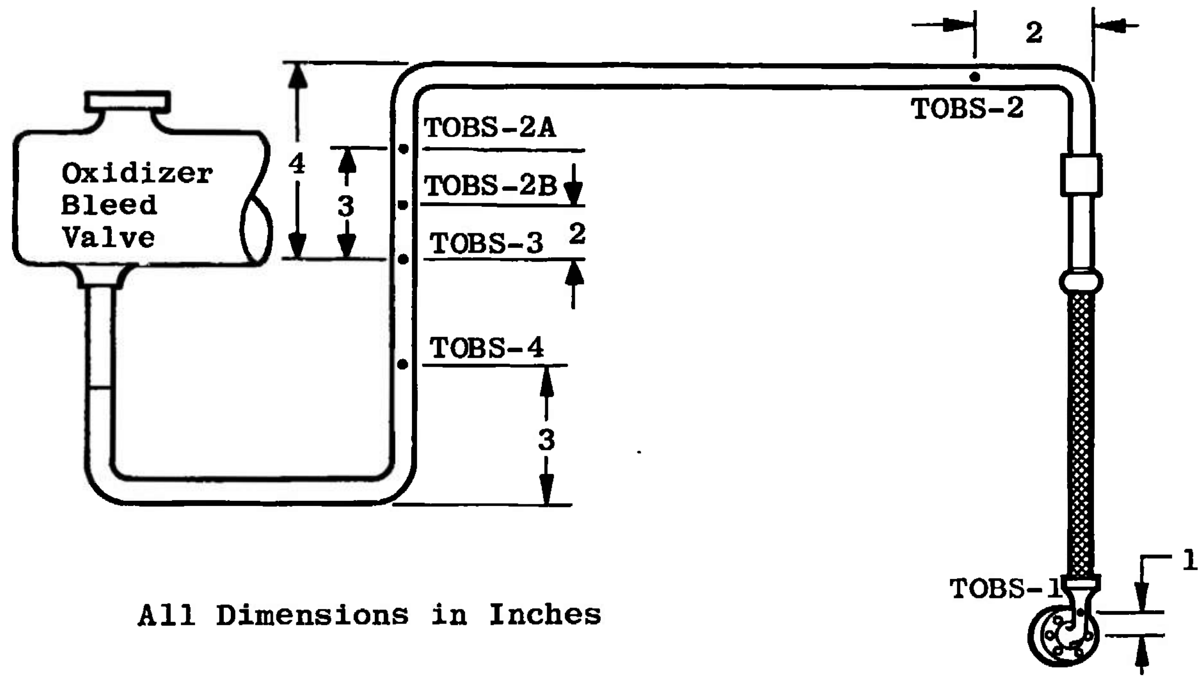


Top View

e. Helium Regulator
Fig. III-1 Continued



f. Thrust Chamber
Fig. III-1 Concluded



g. Oxidizer Bootstrap Line

Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{\dot{W}_{EO}}{\dot{W}_{EF}}$$

$$\dot{W}_{EO} = \dot{W}_{OM} - \dot{W}_{XO}$$

$$\dot{W}_{EF} = \dot{W}_{FM} - \dot{W}_{XF}$$

$$\dot{W}_{E} = \dot{W}_{EO} + \dot{W}_{EF}$$

Thrust Chamber

$$r_C = \frac{\dot{W}_{CO}}{\dot{W}_{CF}}$$

$$\dot{W}_{CO} = \dot{W}_{OM} - \dot{W}_{XO} - \dot{W}_{GO}$$

$$\dot{W}_{CF} = \dot{W}_{FM} - \dot{W}_{XF} - \dot{W}_{GF}$$

$$\dot{W}_{XO} = 0.9 \text{ lb/sec}$$

$$\dot{W}_{XF} = 2.1 \text{ lb/sec}$$

$$\dot{W}_{GO} = \dot{W}_{T} - \dot{W}_{GF}$$

$$\dot{W}_{GF} = \frac{\dot{W}_{T}}{1 + r_G}$$

$$\dot{W}_{T} = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$\dot{W}_{C} = \dot{W}_{CO} + \dot{W}_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{\dot{W}_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$
$$P_{IF} = 30 \text{ psia}$$
$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$
$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$
$$T_{IO} = -295.212\,^\circ\text{F}$$
$$T_{IF} = -422.547\,^\circ\text{F}$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$
$$K_4 = 144$$
$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\, \Delta h_{OFIS}$$
$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$
$$h_{OFIS} = f(P,T)$$
$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$
$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$
$$\eta_{OC} = K_{4O} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{5O} \left(\frac{Q_{PO}}{N_O}\right) + K_{6O}$$
$$K_{4O} = 5.0526$$
$$K_{5O} = 3.8611$$
$$K_{6O} = 0.0733$$
$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} \; H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \; \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\,(P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R_v = A_3 + B_3\,(\theta_{PUVO}) + C\,(\theta_{PUVO})^3 + D_3\,(e)^{\frac{\theta_{PUVO}}{7}} + E_3\,(\theta_{PUVO})\,(e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \; \Delta h_f \; W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} \; H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \gamma_{H2}}{\gamma_{H2}-1} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}}\right] \frac{A_{NB} P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4_{TEF} M_{H2}} \left(\frac{\gamma_{H2}-1}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4{}_{TIF}\, M_{H1}} \; \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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13. ABSTRACT

Nine firings of the J-2 rocket engine were conducted in Test Cell J-4 of the Arnold Engineering Development Center, Large Rocket Facility, during test periods J4-1801-21 and 22. The firings were accomplished at pressure altitudes ranging from 95,000 to 112,000 ft at engine start. The objectives of these tests were to investigate S-II/S-V start condition effects on engine start, gas generator ignition characteristics, and fuel pump operation. Engine thermal condition extremes for S-II flight configuration were duplicated. Satisfactory engine operation was obtained. Accumulated firing duration was 111.6 sec.

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starting characteristics						
gas generators						
fuel pumps						

J-2

1. Rocket motors -- Performance
2 " -- Starting
3 " -- Fuel pump
4 " -- Ignition
5 "
6 Gas generators
7 Fuel pumps
8 missiles -- Saturn II
16-3

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